qnde

Review of Progress in Quantitative Nondestructive Evaluation

E-Book of Abstracts

42nd Annual Review of Progress in Quantitative Nondestructive Evaluation Conference

Hyatt Regency Downtown
Minneapolis, Minnesota
July 26-31, 2015

Organized by
Center for Nondestructive Evaluation
Iowa State University

Updated: 25 July 2015

In cooperation with
American Society for Nondestructive Testing
National Science Foundation Industry/University
Cooperative Research Centers

CENTER FOR NDE

2015 Review of Progress in Quantitative NDE Program Summary
Hyatt Regency Minneapolis (Minneapolis, Minnesota)

	8:30 am – 12:10 pm (Break 10:10)	12:10 pm	1:00 – 6:00 (Break 3:10)	6:00 – 9:00
Saturday July 25	World Federation of NDE Centers — Two Day Short Course "Damage Prognosis for Materials" Sponsored by World Federation of NDE Centers. Organizer: Pradeep Ramuhalli, Pacific Northwest National Laboratory. Lakeshore A			
Sunday July 26	Continuation of WFNDEC Short Course, Lakeshore A	LUNCH	*EAW/BAM Tutorial:* "Introduction to the Evaluation of NDT Systems Through the Calculation of the POD" ~ Daniel Kanzler. Lakeshore A **Conference check-in and registration**	***Welcome Reception*** ***Northstar Ballroom***
Monday July 27	NOTE: Posters will be on display from 3:10 pm. Monday-5:00 pm Thursday Plenary 1: Dr. Joon H. Lee Plenary 2: Dr. Eric Lindgren and Marija Bertovic Nicollet BC	LUNCH	3. Guided Waves I - Nicollet D1 4. Thermography and Thermosonics – Nicollet D2 5. Eddy Current Fundamentals - Nicollet D3 6. 6th EAW – Lakeshore A	***By Invitation*** *World Federation of NDE Centers Board Meeting/Dinner*
Tuesday July 28	7. Guided Waves II - Nicollet D1 8. Additive Manufacturing & Material Characterization - Nicollet D2 9. UT Fundamentals and Composites - Nicollet D3 10. 6th EAW – Lakeshore A	LUNCH	11. Student Poster Session - Nicollet AB 12. NDE in the Railway Branch – - Nicollet D1 13. Microwave, Terahertz, Infrared NDE - Lakeshore C 14. Eddy Current I - Nicollet D3 15. 6th EAW – Lakeshore A 16. Composites I - Nicollet D2	***QNDE Conference Dinner*** ***Northstar Ballroom***
Wednesday July 29	17. Ultrasonic Arrays I - Nicollet D1 18. NDE of Composites II (Experimental) - Nicollet D2 19. NDE and NDT Systems & Civil Eng. Materials - Nicollet D3 20. Signal Processing & New Techniques – Lakeshore C 21. 6th EAW – Lakeshore A	LUNCH	22. Ultrasonic Arrays II and Nonlinear – Nicollet D1 23. NDE Modeling of Composites - Nicollet D2 24. One-Sided Access for Civil Infrastructure Characterization - Nicollet D3 25. Sensors – Lakeshore C 26. 6th EAW – Lakeshore A	Visit Opportunity to U. of Minnesota Earthquake Simulation Lab ***By Invitation*** *I/U CRC Reception and Dinner*
Thursday July 30	27. X-Ray, CT, and Radiographic Methods I – Lakeshore A 28. NDE of Characterization - Nicollet D2 29. Nonlinear Ultrasonics - Nicollet D3 30. Nuclear - Nicollet D1	LUNCH	31. Professional Posters - Nicollet AB 32. X-Ray, CT and Radiographic Methods II - Lakeshore A 33. Pipelines and Automation - Nicollet D1 34. UT Microstructural Scattering - Nicollet D2 35. Benchmarks - Nicollet D3	***Bruce Thompson Memorial 5K FUN RUN*** ***Loring Park***
Friday July 31	36. Non-Contact and Laser Ultrasonics - Nicollet D1 37. Characterization - Nicollet D2 38. Eddy Current II - Nicollet D3 39. Structural Health Monitoring – Lakeshore A			

MONDAY

Plenary Sessions 1 and 2

Review of Progress in Quantitative Nondestructive Evaluation

Hyatt Regency Minneapolis
Minneapolis, Minnesota
July 26 – 31, 2015

PROGRAM
Updated13 July 2015

Monday, July 27, 2015

PLENARY SESSION 1
Leonard J. Bond, Chairperson
Nicollet BC

9:00 AM **Opening Remarks**
---**Leonard J. Bond**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

The Sixth European-American Workshop on Reliability
--Christina Müller, BAM Federal Institute for Materials Research and Testing, Berlin, Germany
--Ralf Holstein, DGZfP, Max-Planck-Str. 6, 12489 Berlin, Germany

9:15 AM **Status and Prospect of NDT Technology for Nuclear Energy Industry in Korea**
---**Joon H. Lee**, Pusan National University, Pusan 609-735, Korea

10:15 AM ***Break***

PLENARY SESSION 2
Dale Chimenti, Chairperson
Nicollet BC

10:30 AM **US Air Force Perspectives on Validated/Reliable NDE – Past, Present, and Future**
---**Eric Lindgren**, USAF AFRL-RXLP-NDE Branch, 2230 10th Street, Bldg. 655, Room 172, WPAFB, OH 45433-7816

11:20 AM **Can Automation Automatically Solve "The Human Factors Problem"?...And Other Illusions**
---**Marija Bertovic**, BAM Bundesanstalt fur, Materialforschung und-prufung, VIII.33, Unter den Eichen 87, Berlin, Germany

12:10 PM ***Lunch***

9:15 AM

Status and Prospect of NDT Technology for Nuclear Energy Industry in Korea

Joon Hyun Lee, Pusan National University, School of Mechanical Engineering, Pusan, Korea 609-735

---Innovative energy technology is considered to be one of the key solutions for meeting the challenges of climate change and energy security, which is why global leaders are focusing on enhancing energy technology R&D. In accordance with the global movements to accelerate energy R&D, the Korean government has made significant investments in a broad spectrum of energy R&D programs, including energy efficiency, resources, CCS, new and renewable energy, power generation and electricity delivery, nuclear power and nuclear waste management. In order to manage government sponsored energy R&D programs in an efficient and effective way, the government established the Korea Institute of Energy technology Evaluation and Planning (KETEP) in 2009. Main activities of KETEP include developing energy technology roadmaps, planning, evaluating, and managing R&D programs, fostering experts in the field of energy, promoting international cooperation programs, gathering and analyzing energy statistics, and supporting infrastructure and commercialization. KETEP assists the Ministry of Trade, Industry and Energy in developing national R&D strategies while also working with researchers, universities, national institutes and the private sector for their successful energy technology and deployment. This presentation consists of three parts. First, I will introduce the characteristics of energy trends and mix in Korea. Then, I'll speak about the related national R&D strategies of energy technology. Finally, I'll finish up with the status and prospect of NDT technology for nuclear energy industry in Korea. The development of the on-line structural integrity monitoring systems and the related techniques in Korean nuclear power plant for the purpose of condition based maintenance is introduced. The needs of NDT techniques for inspection and condition monitoring for GEN IV including SFR, small module reactor etc., are also discussed.

10:30 AM

US Air Force Perspectives on Validated/Reliable NDE – Past, Present, and Future

---**Eric Lindgren**, US Air Force Research Laboratory, Materials and Manufacturing Directorate, Structural Materials Division, Materials State Awareness and Supportability Branch, Wright-Patterson AFB, OH 45433-7816

---The concept of inspection has accompanied aviation since the work of the Wright Brothers. Inspection for both initial quality/materials acceptance and readiness for flight have been coupled with US Air Force (USAF) since its inception as the US Army Signal Corps. Initial nondestructive evaluation work expanded beyond visual inspection to include radiography and magnetic particle in the 1920’s and 1930’s as air frames transitioned to metal and engines used higher strength steels. Within the USAF Research and Development community, a Nondestructive Test Section was stood up in 1952 and the Nondestructive Evaluation Branch (NDE) was established in 1974. In 2012 the name was changed to the Materials State Awareness and Supportability Branch. This name change reflects the evolution from a primary focus on inspections for damage and defects in materials to the characterization of the underlying materials structure that governs properties of the materials of interest for Air Force applications.

This presentation describes the historical developments within the US Air Force that led to current processes to validate the capability of NDE techniques to detect desired flaw sizes and how these inspections are integrated into techniques to ensure USAF structures and propulsion system meet required safety metrics. This includes how NDE techniques are validated, how common classes of capabilities are assessed, and available information and publications addressing common capability throughout the USAF enterprise. In addition, the presentation describes the expansion of required and desired attributes for NDE methods. Materials State Awareness is defined as “digitally-enabled reliable nondestructive quantitative materials and/or damage characterization regardless of scale.” This definition addresses a broad range of features of interest from micro-scale, such as tailored microstructures, to macro-scale, such as the dimensions and location of fatigue cracks or corrosion. Continued developments in materials and processes, including additive manufacturing, combined with initiatives, such as the Materials Genome, highlight the evolving need for materials characterization at an ever finer scale. Extended use of USAF aircraft beyond their original design life highlights the need for damage characterization techniques to safely and affordably sustain assets and enhance evolving Condition-based Maintenance practices. These evolving needs for augmented NDE capability are being addressed with model-driven approaches to overcome challenges due to geometric complexity and variability in typical USAF components. It includes probabilistic treatment of the problems to yield metrics with statistical certainty to enable quantitative diagnostic information for determining risk and accelerate disposition processes. This requires advanced mathematical methods in uncertainty quantification and error propagation coupled with concepts to measure the accuracy of NDE-based characterization techniques. Concepts for realizing these objectives and associated challenges are described in context of this evolving definition of future frameworks for NDE research and development.

11:20 AM

Can Automation *Automatically* Solve "The Human Factors Problem"? …And Other Illusions

---**Marija Bertovic**, DGZfP Education and Training Ltd., Berlin, Germany

---That human performance plays a crucial role in non-destructive evaluation (NDE) has been acknowledged since NDE's beginnings. Hence, continuous efforts are being invested into—among others—personnel training, qualification, certification, inspection procedures, working conditions and the development of technology to assist inspectors in their task. Human factors—in NDE a synonym for the effect of individuals, their experience, training and the conditions under which they have to operate [1]—have been singled out as one of the main contributors to NDE reliability—next to intrinsic capability of the NDE system, the application factors, and the recently introduced organizational context [2]. Typical measures for reducing human variability include more strict inspection procedures as well as an ever-increasing automation of the task. Mechanized testing, for example, is seen as more reliable than manual testing, not only because the data can be stored and, hence, reviewed, but also because of its potential to decrease, if not eliminate, human error. In contrast, the contemporary understanding of reliability and safety reveals a much broader perspective on the role of human factors in high-risk organizations – the emphasis has shifted from focusing on the individual onto focusing on the interaction between all present system components – the individual, the team, the technology, the organization and the extra-organizational environment [3]. Following this rationale, a series of studies has been conducted with the aim of identifying potential risks in interaction with technology, team and organization with emphasis on mechanized testing methods. The results reveal potential for failure in mechanized testing, suggesting that even though automation may reduce failures observed in manual testing, new yet-unknown risks can arise. This talk will provide with an overview of existing theories and approaches to human factors in high-risk organizations with emphasis on the studies conducted in the field of NDE (i.e. identification of risks in mechanized NDT, use of automated aids in the evaluation of data, human redundancy, and optimization of the inspection procedure).---The presented work has been conducted during the author's employment at The Federal Institute for Materials Research and Testing (BAM).

References:

1. T. Taylor and C. Nockemann, "Summary of American-European Workshop on NDE Reliability," in Paper summaries book - American-European Workshop on Nondestructive Inspection Reliability, 21 - 24 September 1999, Boulder, Columbus, OH: The American Society for Nondestructive Testing, Inc., pp. 7–8 (1999).
2. C. Müller, M. Bertovic, M. Pavlovic, D. Kanzler, U. Ewert, J. Pitkänen, and U. Ronneteg, "Paradigm Shift in the Holistic Evaluation of the Reliability of NDE Systems," *Materials Testing*, **55** (4), pp. 261–269 (2013).
3. B. Fahlbruch and B. Wilpert, "System safety - an emerging field for I/O psychology," in *International Review of Industrial and Organizational Psychology*, Volume 14., C. Cooper and I. Robertson, Eds. New York, NY: John Wiley & Sons Ltd., pp. 55–93 (1999).

MONDAY AFTERNOON, JULY 27, 2015

These grid pages are provided for planning purposes. As you go through the program to decide which talks/sessions you would like to attend, you can mark them on this grid for a one shot look at where you would like to go and when on each day of the conference.

	Session 3 **Guided Waves I** ***Nicollet D1***	**Session 4** **Thermography and Thermosonics** ***Nicollet D2***	**Session 5** **Eddy Current Fundaments** ***Nicollet D3***	**Session 6** **Introduction to the 6th EAW; Reliability of SHM** ***Lakeshore A***
1:30 PM				
1:50				
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3:10	COFFEE BREAK			
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Session 3

SESSION 3
GUIDED WAVES I
Peter Cawley and Ronald A. Roberts, Co-Chairpersons
Nicollet D1

1:30 PM **1-D Profiling Using Highly Dispersive Guided Waves**
---**Arno Volker**, Tim van Zon, Mick Hsu, and Lennart Boogert, Stieltjesweg 1, P.O. Box 155, 2600 AD Delft, the Netherlands

1:50 PM **Guided Wave Tomography Performance Analysis**
---**P. Huthwaite,** M. J. S. Lowe, and P. Cawley, Imperial College, Mechanical Engineering Department, South Kensington, London SW7 2AZ, United Kingdom

2:10 PM **SAFE-3D Analysis of a Piezoelectric Transducer to Excite Guided Waves in a Rail Web Large**
---**Dineo A. Ramatlo**[1,2], Philip W. Loveday[1], Craig S. Long[1], and Daniel N. Wilke[2], [1]CSIR Materials Science and Manufacturing; [2]Department of Mechanical and Aeronautical Engineering, University of Pretoria

2:30 PM **The Interaction of the Fundamental Torsional Guided Wave with Gaussian Distributed General Corrosion in Pipes**
---**Jacob Dobson** and Peter Cawley, Imperial College, 318 City & Guilds Building, Exhibition Road, London SW7 2AZ, United Kingdom

2:50 PM **Using Scattering Information to Enhance Sparse Array Imaging of Impact Damage in Composite Materials**
---**Westin B. Williams**, Jennifer E. Michaels, and Thomas E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

3:10 PM ***Break***

3:30 PM **Guided Wave Propagation in Metallic and Resin Plates Loaded with Water on a Single Surface**
---**Takahiro Hayashi** and Daisuke Inouse, Graduate School of Engineering, Kyoto University, Kyoto, 615-8540, Japan

3:50 PM **Multimode Dispersion Compensated Pulse-Echo Guided Wave Inspection**
---**R. Roberts**, L. Koester, and D. Chimenti, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50014

4:10 PM **Guided Wave Attenuation in Coated Pipes Buried in Sand**
---**Eli Leinov**, Michael JS Lowe, and Peter Cawley, NDE Group, Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom

4:30 PM **Optimization of Guided Wave Transducer Arrays for the Inspection of Plate Structures**
---**Alexander Velichko**, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom

4:50 PM **Advanced Signal Processing Methods Applied to Guided Waves for Wire Rope Defect Detection**
---**Javad Rostami** and Peter W. Tse[1], The Smart Engineering Asset Management Laboratory (SEAM) and [1]The Croucher Optical Nondestructive Testing Laboratory (CNDT), Department of Systems Engineering & Engineering Management, City University of Hong Kong, Hong Kong, China

5:10 PM **Domain Decomposition Method for Scattering Problem in 3D Elastic Waveguides**
---**V. Baronian**[1], A.-S. Bonnet-Ben Dhia[2], S. Fliss[2], and A. Tonnoir[1,2], [1]CEA-LIST, Saclay, France; [2]POEMS (UMR 7231 CNRS-ENSTA-INRIA), Palaiseau, France

1:30 PM

1-D Profiling Using Highly Dispersive Guided Waves

---**Arno Volker**, Tim van Zon, Mick Hsu, and Lennart Boogert, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, the Netherlands

---Corrosion is one of the industries major issues regarding the integrity of assets. Currently inspections are conducted at regular intervals to ensure a sufficient integrity level of these assets. Cost reduction while maintaining a high level of reliability and safety of installations is a major challenge. There are many situations where the actual defect location is not accessible, e.g., a pipe support or a partially buried pipe. In case of bottom of the line corrosion, i.e., a single corrosion pit, a simpler approach may be followed. Guided waves are propagated around the circumference of a pipe. In case of wall loss, the phase of the signal changes which is used to estimate the local wall thickness profile. A special EMAT sensor has been developed, which works in a pit-catch configuration at the 12 o'clock position using highly dispersive guided waves. In order to improve the sensitivity, an inversion in performed on multiple orders of circumferential passes. Experimental results are presented on different pipes containing artificial and real defects.

1:50 PM

Guided Wave Tomography Performance Analysis

---P. Huthwaite, M. J. S. Lowe, P. Cawley, Imperial College, Mechanical Engineering Department, South Kensington, London SW7 2AZ, United Kingdom

---Quantifying wall loss caused by corrosion is a significant challenge for the petrochemical industry. Corrosion commonly occurs at pipe supports, where surface access for inspection is limited. Guided wave tomography is being pursued as a solution to this: guided waves are transmitted through the region of interest from an array, and tomographic reconstruction techniques are applied to the measured signals in order to produce a map of thickness. The accuracy of such systems depends on a wide variety of parameters, including the operating frequency, the defect size, depth and shape and the mode used. This talk will present the results of a study across these different parameters to analyze and quantify the performance. Additionally, a benchmarking data set will be provided and discussed; this is offered to enable other researchers to test and compare their own techniques.

2:10 PM

SAFE-3D Analysis of a Piezoelectric Transducer to Excite Guided Waves in a Rail Web

---**Dineo A. Ramatlo**[1,2], Philip W. Loveday[1], Craig S. Long[1], and Daniel N. Wilke[2], [1]CSIR Materials Science and Manufacturing; [2]Department of Mechanical and Aeronautical Engineering, University of Pretoria

---Our existing Ultrasonic Broken Rail Detection system detects complete breaks and primarily uses a propagating mode with energy concentrated in the head of the rail [1]. Previous experimental studies have demonstrated that the head mode, depicted in Figure 1(a), is capable of detecting weld reflections at long distances. Based on numerical work, we feel that we would be able to detect cracks in the rail head. Investigations are underway to extend the system to look for damage before a complete break occurs. Exploiting a mode with energy concentrated in the web of the rail, depicted in Figure 1(b), would allow us to effectively detect defects in the web of the rail and could also help to distinguish between reflections from welds and cracks. In this paper, we will demonstrate the analysis of a piezoelectric transducer attached to the rail web. The forced response at different frequencies is computed by the Semi-Analytical Finite Element (SAFE) method [2] and compared to a full three- dimensional finite element method using ABAQUS. The SAFE method only requires the rail track cross-section to be meshed using two-dimensional elements. The ABAQUS model in turn requires a full three-dimensional discretization of the rail track. The SAFE approach can yield poor predictions at cut-on frequencies associated with other modes in the rail. Problematic frequencies are identified and a suitable frequency range identified for transducer design. The forced response results of the two methods were found to be in good agreement with each other. We then use a previously developed method to analyze a practical transducer over the selected frequency range.

(a) **(b)**

Figure 1. Displacement of the rail cross-section for the head mode (a) and web mode (b).

References:

1. Francois A. Burger, Philip W. Loveday, and Craig S. Long, "Large scale implementation of guided wave based broken rail monitoring," *41st Annual Review of Progress in Quantitative Nondestructive Evaluation, AIP conference proceedings*, 1650, 771-776, 2015.

2. Takahiro Hayashi, Won-Joon Song, and Joseph L Rose, "Guided wave dispersion curves for a bar with an arbitrary cross-section, a rod and rail example," *Ultrasonics*, 41(3):175_183, May 2003.

2:30 PM

The Interaction of the Fundamental Torsional Guided Wave with Gaussian Distributed General Corrosion in Pipes

---**Jacob Dobson** and Peter Cawley, Imperial College, 318 City & Guilds Building, Exhibition Road, London SW7 2AZ, United Kingdom

---Field experience shows that general corrosion in pipes causes increased attenuation and increased background noise during guided wave inspection (see figure 1). This causes a reduction in the effective inspection range and reduces sensitivity to defects in the region of the general corrosion. Finite element simulations have been used to better understand these effects and quantify the interaction of the fundamental torsional guided wave with different corrosion surfaces. This general corrosion is modelled as a Gaussian random surface parametrized by a mean depth and correlation length. Three depths of corrosion and twenty different correlation lengths are simulated, in each case with ten random surfaces generated at each condition to obtain average behavior. An efficient GPU based parallel solver is then used to solve for the interaction of guided waves of different frequency with these surfaces. It was found that energy in the fundamental torsional wave is strongly scattered to higher order flexural waves at the cut-off frequencies of these higher order waves. Away from cut-off frequencies the scattering is greater at higher frequencies since there are more possible modes for the energy to scatter into. It was also found that energy scattering is strongest when the correlation length of the surface is around 0.25 times the wavelength of the incident wave (for a given frequency). The scattering is also more significant for corrosion with greater mean depth. This scattering explains the apparent attenuation of the guided wave; energy is being lost to higher order modes which are not measured in commercial guided wave systems. The simulations are validated through an analysis of the energies transmitted and received from the model. The simulations are also validated experimentally through machining of an example corrosion surface on a pipe specimen.

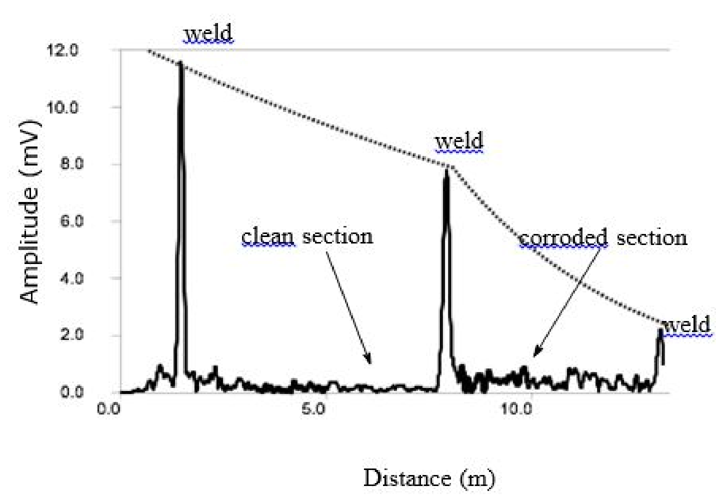

Figure 1. Guided wave reflection from a pipe containing a clean section and a generally corroded section.

2:50 PM

Using Scattering Information to Enhance Sparse Array Imaging of Impact Damage in Composite Materials

---**Westin B. Williams**, Jennifer E. Michaels, and Thomas E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

---Impacts to composite structures can often produce internal damage not visible on the surface. Since this damage can compromise the integrity of the structure, it is important that it be detected promptly. One approach for detecting damage with guided waves is sparse array imaging after baseline subtraction [1]. This method can be applied by permanently attaching sensors to a structure for performing structural health monitoring. However, its performance in detecting and localizing damage can vary according to the size and location of damage within the array. Prior work has demonstrated that knowledge of expected scattering patterns can significantly improve sparse array imaging results [2], which could help mitigate performance issues. For this study, a series of impact tests are performed on a solid laminate composite panel. These data are used to estimate scattering patterns from impact damage, which are then incorporated into sparse array imaging algorithms. In addition, axially symmetric scatterers of various materials and profiles are temporarily attached to simulate damage, and their scattering characteristics are compared to those from actual impact damage. It is shown that sparse array imaging results are significantly improved when using accurate scattering patterns, particularly within the transducer bounding polygon. Results are compared to those obtained from both wavefield imaging and air-coupled C-scans.---This work is funded by the National Aeronautics and Space Administration (NASA) under Grant No. NNX12AL13A (Dr. Cara Leckey, Program Manager).

References:

1. J. E. Michaels, "Detection, localization and characterization of damage in plates with an *in situ* array of spatially distributed ultrasonic sensors," *Smart Materials and Structures*, 17, 035035 (15pp), 2008.
2. J. S. Hall, P. Fromme, and J. E. Michaels, "Guided wave damage characterization using a distributed array of ultrasonic sensors," Journal of Nondestructive Evaluation, 33, pp. 299-308, 2014.

3:30 PM

Guided Wave Propagation in Metallic and Resin Plates Loaded with Water on a Single Surface

---Takahiro Hayashi and Daisuke Inoue, Graduate School of Engineering, Kyoto University, Kyoto, 615-8540, Japan

---We presented dispersion curves for leaky Lamb waves in a water-loaded plate and wave structures for several typical modes including quasi-Scholte waves [1, 2]. The calculations were carried out with a semi-analytical finite element (SAFE) method developed for leaky Lamb waves. This study shows SAFE calculations for transient guided waves including time-domain waveforms and animations of wave propagation in metallic and resin water-loaded plates. The calculation results provide that non-dispersive and non-attenuative waves propagating along the interface between fluid and a plate are expected for effective non-destructive evaluation of such fluid-loaded plates as storage tanks and transportation pipes. We calculated transient waves in both steel and resin plates loaded with water on a single side and input dynamic loading from a point source on the other water-free surface. For a steel plate, the non-dispersive and non-attenuative mode is quasi-Scholte wave that has almost identical phase velocity to that of water. The quasi-Scholte wave has superior generation efficiency in low frequency range due to its broad energy distribution across the plate thickness, while it is localized near the plate-water interface at higher frequencies, which means that it has superior detectability of inner defects. For a resin plate that has smaller material constants and lower acoustic impedance close to that of water, small dispersive and non-attenuative modes have properties of Rayleigh wave and quasi-Scholte wave.**---**The work is funded by the JSPS KAKENHI Grant Number 26282094.

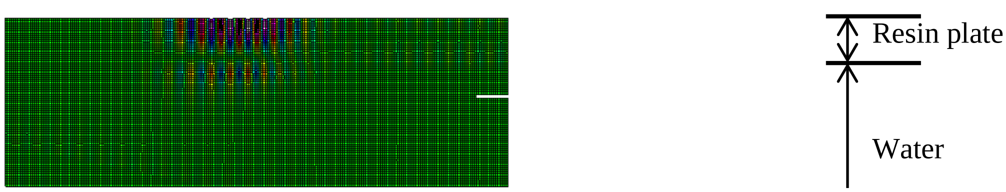

Figure 1. Wave propagation in a resin plate loaded with water on a single surface.

References:

1. T. Hayashi, D. Inoue, "Calculation of leaky Lamb waves with a semi-analytical finite element method," Ultrasonics. 54 (6). pp. 1460-1469 (2014).
2. T. Hayashi, D. Inoue, "Numerical analysis of leaky Lamb wave propagation using a semi-analytical finite element method," in Review of Progress in Quantitative Nondestructive Evaluation, eds., D. E. Chimenti and L. J. Bond (American Institute of Physics 1430, Melville, NY), 1650, pp.695-702, (2015).

3:50 PM

Multimode Dispersion Compensated Pulse-Echo Guided Wave Inspection

---**R. Roberts**, L. Koester, D. Chimenti, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50014

---Obtaining temporal/spatial resolution in guided wave measurements comparable to that of bulk wave measurements is impeded by the complicating effects of multimode dispersion. Transport of signals by multiple dispersive modes of propagation can transform an initially compact transient into an extended, visually unintelligible wavetrain. Guided mode inspections therefore tend to restrict measurements to regimes for which a single mode can be generated with minimal dispersion, consequently restricting the achievable temporal/spatial resolution of the measurement. The objective of the work reported here is to remove such restrictions, through implementation of wavefield measurements which accommodate the total complexity of multimode dispersed signals. Temporal and spatial Fourier analysis of guided wave fields enables a full identification of individual mode contributions, as well as associated mode dispersion characteristics, as has been demonstrated by numerous researchers. Practical implementation of spatial Fourier analysis can be achieved using appropriately designed array transducers. It is therefore conceivable that, for a given measurement configuration, processing could be implemented to effectively remove the effects of multimode dispersion, enabling operation in frequency regimes currently associated with bulk wave measurements. This paper will report on work which is exploring this possibility. Results will be presented demonstrating array-based MHz regime plate wave measurements, generating 10 or more modes, in which individual modes are isolated, effects of dispersion are removed, and temporal resolution of the original transmitted pulse is restored. Application to improved defect resolution in canonical guided wave measurements will be discussed.---This material is based on work supported by the Iowa State University Center for Nondestructive Evaluation NSF Industry-University Cooperative Research Center.

4:10 PM

Guided Wave Attenuation in Coated Pipes Buried in Sand

---**Eli Leinov**, Michael JS Lowe, and Peter Cawley, NDE Group, Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom

---Long-range guided wave testing (GWT) is routinely used for the monitoring and detection of corrosion defects in aboveground pipelines in various industries. The GWT test range in buried, coated pipelines is greatly reduced compared to aboveground pipelines due to energy leakage into the embedding soil. In this study, we aim to increase test ranges for buried pipelines. The effect of pipe coatings on the T(0,1) and L(0,2) guided wave attenuation is investigated using a full-scale experimental apparatus and model predictions. Tests are performed on a fusion-bonded epoxy (FBE)-coated 8” pipe, buried in loose and compacted sand over a frequency range of 10-35 kHz. The application of a low impedance coating is shown to effectively decouple the influence of the sand on the ultrasound leakage from the buried pipe. We demonstrate ultrasonic isolation of a buried pipe by coating the pipe with a Polyethylene (PE)-foam layer that has a smaller impedance than both pipe and sand and the ability to withstand the overburden load from the sand. The measured attenuation in the buried PE-foam-FBE-coated pipe is substantially reduced, in the range of 0.3-1.2 dBm^{-1} for loose and compacted sand conditions, compared to buried FBE-coated pipe without the PE-foam, where the measured attenuation is in the range of 1.7-4.7 dBm^{-1}. The acoustic properties of the PE-foam are measured independently using ultrasonic interferometry technique and used in model predictions of guided wave propagation in a buried coated pipe. Good agreement is found between the attenuation measurements and model predictions. The attenuation exhibits periodic peaks in the frequency domain corresponding to the through-thickness resonance frequencies of the coating layer. The large reduction in guided wave attenuation for PE-coated pipes would lead to greatly increased GWT test ranges, so such coatings would be attractive for new pipeline installations.

4:30 PM

Optimization of Guided Wave Transducer Arrays for the Inspection of Plate Structures

---Alexander Velichko, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom

---The paper describes a general approach for processing data from a guided wave transducer array on a plate-like structure. The raw data set from such an array contains time-domain signals from each transmitter–receiver combination. The problem of finding optimal array element layout, which allows the number of elements and amount of measured transmitter– receiver signals to be minimized without compromising array performance, is considered. Previously it has been shown that performance of fully populated array in the far field can be achieved by using sparse array with the elements located along the perimeter of the original array [1,2]. However, the problem of optimal element spacing hasn't been fully investigated. Based on numerical calculations it has been hypothesized that for sparse array the element spacing must follow the classical Nyquist–Shannon sampling theorem. In this paper it is shown that in the case of the far field imaging the signal can be reconstructed with much fewer array elements than the sampling theorem requires. A new sampling criterion is derived and an optimized sparse array layout is proposed. The theory is validated experimentally using a guided wave array containing electromagnetic acoustic transducer elements for exciting and detecting the *S*0 Lamb wave mode in a 5-mm-thick aluminum plate.

References:

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4:50 PM

Advanced Signal Processing Methods Applied to Guided Waves for Wire Rope Defect Detection

---**Javad Rostami** and Peter W. Tse[1], The Smart Engineering Asset Management Laboratory (SEAM) and [1]The Croucher Optical Nondestructive Testing Laboratory (CNDT), Department of Systems Engineering & Engineering Management, City University of Hong Kong, Hong Kong, China

---Steel wire ropes with a polymer core that hold and hoist heavy loads in different structures such as clamshells, draglines, elevators, etc. work under fluctuating forces in a corrosive environment. This consequently leads to progressive loss of the metallic cross-section due to abrasion and corrosion which can be seen in the forms of roughened and pitted surface of the ropes, reduction in diameter, and broken wires. Therefore, their deterioration must be monitored so that any unexpected damage or corrosion can be detected before it causes fatal accident. This is of vital importance in the case of passenger transportation, particularly in elevators in which any failure may cause a catastrophic disaster. At the moment, widely used methods for thorough inspection of wire ropes in order to detect probable anomalies include visual inspection and magnetic flux leakage (MFL). Reliability of the first method can be questioned since it only depends on the operators' eyes and fails to determine the integrity of internal wires. The later method has the drawback of being point by point, which is time-consuming. Ultrasonic guided wave (UGW) based inspection, which has proved its capability in non-destructive testing of plate like structures such as tubes and pipes, can monitor the cross-section of wire ropes in their entire length from a single point. However UGW have drawn less attention for defect detection purposes in wire ropes. This paper reports the condition monitoring of a steel wire rope from a hoisting elevator with broken wires as a result of corrosive environment and fatigue. Experiments were conducted to investigate the efficiency of using magnetostrictive based UGW for rope defect detection. The obtained signals were analyzed by two time-frequency representation (TFR) methods– the Short Time Fourier Transform (STFT) and the Wavelet-analysis. The location of the defect and its severity were successfully identified and characterized.---The work described in this paper was fully supported by a grant from the Research Grants Council (Project No. CityU _122513) and a grant from the Innovation and Technology Commission (Project No. ITS/061/14FP) of the Government of Hong Kong Special Administrative Region, China.

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Domain Decomposition Method for Scattering Problem in 3D Elastic Waveguides

---**V. Baronian**[1], A.-S. Bonnet-Ben Dhia[2], S. Fliss[2] and A. Tonnoir[1,2], (1) CEA-LIST, Saclay, France --- (2) POEMS (UMR 7231 CNRS-ENSTA-INRIA), Palaiseau, France

---In this work, we consider the time-harmonic diffraction problem by an arbitrary localized defect in an elastic waveguide. Usually, two classical approaches can be used to bound the scattering domain surrounding the defect. The first one is absorbing layers (constituted a viscoelastic materials) which leads to solve a sparse but large linear system. The second one is a hybrid method [1] involving a coupling operator between the Finite Element (FE) and the Modal representations of the diffracted solution. Unfortunately, due to the dense structure of the coupling operator, this approach gives rise to a small but partially dense linear system that can induce prohibitive computational (LU factorization) cost, especially for large 3D configurations. Our aim is to propose an original method that gathers advantages of the two previous approaches (inversion of a small and sparse matrix). Therefore, a new hybrid FE/Modal boundary operator has been designed, where the matching between the two representations is done on two separated boundaries and is said “with overlap" by analogy with the domain decomposition methods. This approach has been already used in the case of acoustic waveguide [2] and is more suitable for an iterative resolution (since the convergence rate classically depends of the size of the overlap). Among the most significant advantages, the possibility to handle large 3D systems and general anisotropic elastic cases, are offered by this latter approach. Numerical illustrations will be presented on various 3D realistic NDT configurations.

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Session 4

SESSION 4
THERMOGRAPHY AND THERMOSONICS
Xiaoyan Han and Stephen D. Holland, Co-Chairpersons
Nicollet D2

1:30 PM **Determination of Flaw Size and Depth from Temporal Evolution of Thermal Response**
---William P. Winfree, Elliott Cramer, **Joseph N. Zalameda**, and Patricia A. Howell, Mail Stop 225, 5 West Taylor Street, NASA Langley Research Center, Hampton, VA 23681

1:50 PM **Thermal Property Measurement for Thermal Barrier Coatings Using Pulsed Thermal Imaging – Multilayer Analysis Method**
---**J. G. Sun**[1] and N. Tao[2], [1]Argonne National Laboratory, Argonne, IL 60439; [2]Capital Normal University, Beijing, China

2:10 PM **Multilayer Material Characterization Using Thermographic Signal Reconstruction**
---**Steven Shepard** and Maria Frendberg-Beemer, Thermal Wave Imaging, Inc., Ferndale, MI 48220

2:30 PM **Analysis of Non-contact Acousto-Thermal Signature Data**
---**Amanda Keck Criner** and Norm Schehl, DR-02 USAF AFMC AFRL/RXCA, Wright Patterson AFB, OH 45433

2:50 PM **Evaluation of SonicIR Handheld System on Composite Impact Damage Detection**
---**Xiaoyan Han**, Justin M. Ar-Rasheed, Ding Zhang, and Anthony Lubowicki, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Dr. #3123, Detroit, MI 48202

3:10 PM ***Break***

3:30 PM **VibroSim: A Hybrid Computational/Empirical Model of Vibrothermography Nondestructive Evaluation**
---**Stephen D. Holland**, Lucas Koester, Jyani Vaddi, Tyler Lesthaeghe, and Brian Schiefelbein, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50014

3:50 PM **Determining Energy Dissipation Rate from Surface Temperature for Vibrothermography Modeling**
--- **Stephen D. Holland**, Tyler Lesthaeghe, and Stephen D. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50014

4:10 PM **Empirical Modeling of Vibrothermographic Crack Heating**
---**Tyler Lesthaeghe**[1,2], Jyani Vaddi[1,2], Bryan Schiefelbein[1,2], Stephen D. Holland[1,2,] William Q. Meeker[1,3] and Ashraf Bastawros[1,2], Center for Nondestructive Evaluation[1], Department of Aerospace Engineering[2], and Department of Statistics[3], Iowa State University, Ames, IA 50011

4:30 PM **Develop Algorithms to Improve Detectability of Defects in Sonic IR Imaging NDE**
---Qiuye Yu, Omar Obeidat, and **Xiaoyan Han**, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Dr., #3123, Detroit, MI 48202

4:50 PM **Examination of Spot Welded Joints with Active Thermography**
---**Florian Jonietz**[1], Mathias Ziegler[1], Philipp Myrach[1], Hubert Suwala[2], and Michael Rethmeier[1,2], [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany; [2]Fraunhofer Institute for Production Systems and Design Technology, Berlin, Germany

5:10 PM **Open**

1:30 PM

Determination of Flaw Size and Depth from Temporal Evolution of Thermal Response
---William P. Winfree, Elliott Cramer, **Joseph N. Zalameda**, and Patricia A. Howell, Mail Stop 225, 5 West Taylor Street, NASA Langley Research Center, Hampton, VA 23681

---Simple methods for reducing the pulsed thermographic responses of flaws have tended to be based on either the spatial or temporal response. This independent assessment limits the accuracy of characterization. A variation approach is presented for reducing the thermographic data to produce an estimated size for a flaw that incorporates both the temporal and spatial response to improve the characterization. The size and depth are determined from both the temporal and spatial thermal response of the exterior surface above a flaw and constraints on the length of the contour surrounding the delamination. Examples of the application of the technique to simulation and experimental data acquired are presented to investigate the limitations of the technique.

1:50 PM

Thermal Property Measurement for Thermal Barrier Coatings Using Pulsed Thermal Imaging – Multilayer Analysis Method

---**J. G. Sun**[1] and N. Tao[2], [1]Argonne National Laboratory, Argonne, IL 60439; [2]Capital Normal University, Beijing, China

---Thermal barrier coatings (TBCs) are extensively used on hot gas-path components in gas turbines to improve engine performance and extend component life. TBC thermal properties, specifically the thermal conductivity and heat capacity (the product of density and specific heat), are important parameters in these applications. These TBC properties are usually measured by destructive methods with specially prepared TBC samples. Nondestructive evaluation (NDE) methods have been developed in recently years that can measure TBC properties on natural TBC samples. However, many have limitations when examining TBCs on engine components. One exception is the pulsed thermal imaging – multilayer analysis (PTI-MLA) method, which can be applied to essentially any TBC samples with one or more coating layers and can determine TBC property distributions over the entire TBC surface. In this presentation, we will describe the basic theories and assumptions in the PTI-MLA method. We show an experimental validation of its measurement accuracy for the coating's thermal effusivity. We then demonstrate its applications for the NDE measurement of TBC properties on coupons as well as on an engine component.

2:10 PM

Multilayer Material Characterization Using Thermographic Signal Reconstruction
---**Steven Shepard** and Maria Frendberg-Beemer, Thermal Wave Imaging, Inc., Ferndale, MI 48220

---Active thermography is widely used for subsurface flaw detection, based on visual or numerical analysis of flaw-background contrast in the infrared video image sequence of an actively heated test sample as it cools to equilibrium. Several methods, e.g. Pulse Phase and Principal Component Analysis, have been shown to improve contrast, as well as sensitivity and depth range by processing each pixel time history in the time or frequency domain. The Thermographic Signal Reconstruction (TSR) method is unique in that a significant amount of information about the local subsurface state of the sample can be obtained from a single pixel time history without the use of calibration standards or comparison to other pixels. In TSR a noise-reduced replica of each pixel time history is created by a least squares fit of a low order polynomial. The logarithmic derivative of each replica is computed, and images are created based on the derivative amplitude at a particular time, or attributes of the derivatives (e.g. amplitudes or times at which extrema or threshold crossings occur). The resulting logarithmic derivative images yield significant enhancement of flaw-background contrast, providing improved detection of weak subsurface features (e.g. porosity or kissing bonds), which may not generate sufficient contrast to be visually detectable in the conventional IR image sequence. The derivative time histories can be classified according to a set of signal primitives in the 1st or 2nd derivative. Qualitative analysis of a flaw-free multilayer sample may be achieved by comparison of the number, order and polarity of the extrema and zero crossings of the derivative signal with the primitives. Measurement of derivative amplitudes allows quantitative characterization of layer thermal properties.

2:30 PM

Laser Spot Thermography for Fatigue Crack Detection

---Jakub Roemer, Łukasz Pieczonka, and Tadeusz Uhl. AGH University of Science and Technology, Department of Robotics and Mechatronics. Al. A. Mickiewicza 30, 30-059 Kraków

---The paper investigates an application of laser spot thermography for nondestructive characterization of cracks in engineering materials [1]. Two experimental cases are considered, namely the detection of cracks in glass samples and fatigue cracks in aluminum. Vibrothermography is used to provide reference results. The paper presents an automated test rig for laser spot thermography consisting in an infrared camera, diode laser source, Cartesian positioning system and a suitable control software. In addition, the semi-automatic algorithm for measurement data processing is presented. The algorithm significantly reduces the post processing time, by limiting the operator input to a minimum, and provides reliable information on the damage state of an inspected material. It is shown that laser spot thermography can be effectively used to characterize cracks in both aluminum and glass samples.

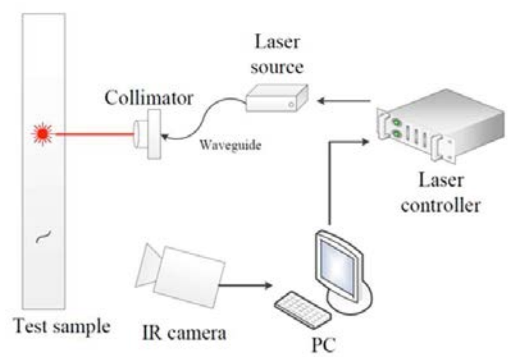

Figure 1. Laser spot thermography test setup [2].

References:

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2:50 PM

Evaluation of SonicIR Handheld System on Composite Impact Damage Detection

---**Xiaoyan Han**, Justin M. Ar-Rasheed, Ding Zhang, and Anthony Lubowicki, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Dr. #3123, Detroit, MI 48202

---Sonic Infrared (IR) Imaging has shown its capability as a fast, wide area NDE method. We have demonstrated its wide applications to different types of materials and structures. Along the path of the development of this technology, we have studied the effect of the input UT source transducer frequency, heating mechanism of different types of defects, the role coupling materials, the non---linear phenomena, the effect of crack closure, etc. The WSU team has also been developing prototypes of this technology for future in field inspection. In this paper, we will present the evaluation of the system with structured composite samples containing widespread impact damages.---This work was sponsored by the Federal Aviation Administration William J. Hughes Technical Center under Contract Number DTFACT-08-C-00043 with Agency Contract Number 437-65061, and in part by Wayne State University. The impact samples were provided by Robert Barry from Bell Helicopter.

3:30 PM

VibroSim: A Hybrid Computational/Empirical Model of Vibrothermography Nondestructive Evaluation

---**Stephen D. Holland**, Lucas Koester, Jyani Vaddi, Tyler Lesthaeghe, and Brian Schiefelbein, Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50014
---Vibrothermography is a nondestructive evaluation technique that finds cracks through vibration-induced heating of contacting crack surfaces. Because there are multiple phenomena involved: vibration, vibration-induced heating, and heat flow, all three processes must be accurately represented in individually tested components in order to create a meaningful model of the entire process. Finite element models are suitable for the well-understood vibrational and heat flow modeling components. With the phenomenology of the heat generation component still unclear, an empirical model was used to relate the dynamic engineering strain from the vibration to the crack heating itself. All three components are integrated into a single COMSOL model generated by a collection of MATLAB scripts.---This material is based on work supported by the Air Force Research Laboratory under Contract #FA8650-10-D-5210, Task Order #023 and performed at Iowa State University

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Determining Energy Dissipation Rate from Surface Temperature for Vibrothermography Modeling

---**Jyani Vaddi**, Tyler Lesthaeghe, and Stephen D. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50014

---An algorithm to calculate energy dissipation rate at a crack in vibrothermography is proposed. Calculating heat dissipation from measured temperature is generally ill-posed because of the inherent diffusive nature of heat conduction, especially in metals where the thermal conductivity is high. The thermal image gets blurred because of thermal diffusion, so resolving the exact position of heat generation along the crack is not trivial. However, immediately after the onset of vibration, there has not been enough time for heat to diffuse, so pattern of near-surface heating can be resolved and the measured temperature can be efficiently inverted. We model the crack as a series of concentric semi-annular rings centered with the crack. Based on the heat flow simulation, we represent the surface temperature as a linear function of the heating power of all the individual rings, then invert this linear function to evaluate heating power as a function of surface temperature. This algorithm is only valid for the hypothesized semi-annular ring heating pattern and would perform poorly if crack heating does not follow this assumption.

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Empirical Modeling of Vibrothermographic Crack Heating

---Tyler Lesthaeghe[1,2], Jyani Vaddi[1,2], Bryan Schiefelbein[1,2], Stephen D. Holland[1,2], William Q. Meeker[1,3,] and Ashraf Bastawros[1,2], Center for Nondestructive Evaluation[1], Department of Aerospace Engineering[2], and Department of Statistics[3], Iowa State University, Ames, IA 50011

---Vibrothermography is a nondestructive testing technique that uses vibration-induced heating to locate cracks inside parts. Industrial application of vibrothermography has typically been limited by a lack of complete understanding of the factors influencing vibrothermographic crack heating. Vibrothermography includes three physical processes: vibration, vibration-induced crack heating, and heat flow. This paper outlines the development of an empirical model of the vibration-induced crack heating process, incorporated as a component of a complete model of vibrothermography (the vibration and heat flow models are based on finite element). The empirical model describes heating as a multiplicative function of vibrational energy, crack relative mobility, and crack closure. A series of measurements inform the empirical model for a sample of cracks. Maximum likelihood estimation is used to fit model parameter estimates from measured data for each of the cracks. A second-stage Bayesian model is used to link the information among the cracks and describe crack-to-crack variability. A posterior predictive distribution of heating can then be computed as a function of crack characteristics, enabling the empirical model to predict heat generation from vibration. This empirical model combines with finite element vibration and heat flow models to create a complete forward model of the vibrothermography process.---This material is based on work supported by the Air Force Research Laboratory under Contract #FA8650-10-D-5210, Task Order #023 and performed at Iowa State University, Case Number 88ABW-2015-2523

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Develop Algorithms to Improve Detectability of Defects in Sonic IR Imaging NDE

---Qiuye Yu, Omar Obeidat, and **Xiaoyan Han**, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Dr., #3123, Detroit, MI 48202

---Sonic Infrared (IR) technology is relative new in the NDE family. It is a fast, wide area imaging method. It combines ultrasound excitation and infrared imaging while the former to apply ultrasound energy thus induce friction heating in defects and the latter to capture the IR emission from the target. This technology can detect both surface and subsurface defects such as cracks and disbonds/delaminations in various materials, metal/metal alloy or composites. However, certain defects may results in only very small IR signature and are buried in noise or heating patterns. In such cases, to effectively extract the defect signals becomes critical in identifying the defects. In this paper, we will present algorithms which are developed to improve the detectability of defects in Sonic IR.--- This work is sponsored by Wayne State University.

4:50 PM

Examination of Spot Welded Joints with Active Thermography

---**Florian Jonietz**[1], Mathias Ziegler[1], Philipp Myrach[1], Hubert Suwala[2], and Michael Rethmeier[1,2], [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany; [2]Fraunhofer Institute for Production Systems and Design Technology, Berlin, Germany

---Spot welding is one of the most important joining technologies, especially in the automotive industry. Hitherto, the quality of spot welded joints is tested mainly by random destructive tests. A nondestructive testing technique offers the benefit of cost reduction of the testing procedure and optimization of the fabrication process, because every joint could be examined. This would lead to a reduced number of spot welded joints, as redundancies could be avoided. In the procedure described here, the spot welded joint between two zinc-coated steel sheets (HX340LAD+Z100MB or HC340LA+ZE 50/50) is heated optically on one side. Laser radiation and flash light are used as heat sources. The melted zone, the so called “weld nugget” provides the mechanical stability of the connection, but also constitutes a thermal bridge between the sheets. Due to the better thermal contact, the spot welded joint reveals a thermal behavior different from the surrounding material, where the heat transfer between the two sheets is much lower. The difference in the transient thermal behavior is measured with time resolved thermography. Hence, the size of the thermal contact between the two sheets is determined, which is directly correlated to the size of the weld nugget, indicating the quality of the spot weld. The method performs well in transmission with laser radiation and flash light. With laser radiation, it works even in reflection geometry, thus offering the possibility of testing with just one-sided accessibility. By using heating with collimated laser radiation, not only contact-free, but also remote testing is feasible. A further convenience compared to similar thermographic approaches is the applicability on bare steel sheets without any optical coating for emissivity correction. For this purpose, a proper way of emissivity correction was established.---The IGF-project 17686 N of the Research Association for Steel Application – FOSTA, Sohnstraße 65, 40237 Düsseldorf, was funded via AiF by the Federal Ministry for Economic Affairs and Energy (BMWi) within the framework of the program Industrial Collective Research (IGF) on the basis of a decision of the German Bundestag.

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Analysis of Non-contact Acousto-Thermal Signature Data

---**Amanda Keck Criner**[1] and Norm Schehl[2], [1]Air Force Research Labs, Materials and Manufacturing Directorate, Wright Patterson AFB OH 45433; [2]Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

---The non-contact acousto-thermal signature (NCATS) is a nondestructive evaluation technique with potential to detect fatigue in materials such as titanium alloys and polymer matrix composites. The determination of the underlying physical mechanisms is complicated by the subtleties of the analysis of data collected in these experiments including the ill-posed nature of the inverse problem. An initial model for proof of concept data analysis will be introduced along with data based justifications of the assumptions implicit in the model formulation. A parameter estimation scheme with spatial and temporal independent variables will be discussed. The resulting parameter estimates from this scheme will be evaluated with respect to the accuracy of the implicit assumptions. Future work will be discussed including changes to the experimental setup that will simplify data analysis.

Session 5

SESSION 5
EDDY CURRENT FUNDAMENTALS
John Bowler, Chairperson
Nicollet D3

1:30 PM **Exploiting Resonant Frequency Shifts for Novel Eddy-Current Techniques**
---**Robert Hughes**[1] and Steve Dixon[1], [1]University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

1:50 PM **Experimental Validation of an Eddy Current Probe for Defect Detection in Thick Conducting Specimen**
---**Mahesh Raja P**[1], Kavitha Arunachalam[2], [3]Krishnan Balasubramanian[3], [1,2]Department of Engineering Design, [3]Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India-600036

2:10 PM **Eddy Current Testing in Environments that Limit Performance**
--John Bowler, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

2:30 PM **Model-Based Inverse Methods for Sizing Surface-Breaking Discontinuities with Eddy Current Probe Variability**
---**John C. Aldrin**, Computational Tools, Gurnee, IL, 60031; Eric B. Shell and Erin K. Oneida, Wyle, Dayton, OH 45440; Harold A. Sabbagh, Elias Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Siamack Mazdiyasni and Eric A. Lindgren, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

2:50 PM **Numerical Modeling of Eddy Current Testing of U-Shaped Tubes by Differential Geometry**
---Saptarshi Mukherjee[1], **Antonello Tamburrino**[1,2], Naiguang Lei[1], Lalita Udpa[1] and Satish Udpa[1], [1]Nondestructive Evaluation Laboratory, Michigan State University, Michigan 48824 [2]DIEI, Università degli Studi di Cassino V. G. Di Biasio, 43 Cassino 03043, Italy

3:10 PM ***Break***

3:30 PM **WITHDRAWN - Numerical Simulation in ACFM Inducer Design -**
---**Wenpei Zheng** and Laibin Zhang, China University of Petroleum-Beijing, 18 Fuxue Road, Changping, Beijing, 102249, China; Taian Fang and Zhixiong Zhou, CNPC Drilling Research Institute, Block A34 CNPC Innovation Centre, W of Xishatun Bridge Shahe Town, Changping District, Beijing, 102206, China

3:50 PM **Characterizing Surface Features on Conducting Specimens Through an Insulation Layer Using Capacitive Imaging Technique**
---**Xiaokang Yin**, An Yan, Zhen Li, Wei Li, and Guoming Chen, Centre for Offshore Equipment and Safety Technique, China University of Petroleum (East China), Qingdao 266580, China; David A. Hutchins, School of Engineering, Warwick University, Coventry CV4 7AL, United Kingdom

4:10 PM **Monotonicity of Time-Constants and Real-Time Imaging in Eddy Current Testing**
---Zhiyi Su[1], **Antonello Tamburrino**[1,2], Salvatore Ventre[2], Lalita Udpa[1] and Satish Udpa[1]. [1]Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824. [2]DIEI, Università di Cassino e del Lazio Meridionale, 03043, Cassino, Italy

4:30 PM **3-D Finite Element Modelling of Eddy Current Inspection of Surface EDM Notches Using a Reflection Differential Split-D Probe**
---**Ehsan Mohseni**[1], Demartonne Ramos França[1], Martin Viens[1], Wen Fang Xie[2], Baoguang Xu[2] [1]Départment de génie mécanique, L'École de technologie supérieure, Montréal, Québec, Canada [2]Department of Mechanical & Industrial Engineering, Concordia University, Montreal, Quebec, Canada

4:50 PM **In-Situ Calibration of Pulsed Eddy Current Detection of Cracks at Fasteners in CP-140 Aircraft**
---**P. R. Underhill**, C. Stott, and T.W. Krause, Department of Physics, Royal Military College of Canada, Kingston, ON, K7K 7B4, Canada

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1:30 PM

Exploiting Resonant Frequency Shifts for Novel Eddy-Current Techniques

---**Robert Hughes**[1] and Steve Dixon[1], [1]University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---The sensitivity enhancing effects of eddy-current testing at frequencies close to electrical resonance are explored. Varied techniques exploiting the phenomenon, dubbed near electrical resonance signal enhancement (NERSE), were experimentally investigated to evaluate its potential exploitation for other interesting applications in aerospace materials, in particular it's potential for boosting the sensitivity of standard ECT measurements. Methods for setting and controlling the typically unstable resonant frequencies of such systems were explored for the purposes of tuneable eddy-current array probes. The results of these studies are discussed.---This research is funded by the EPSRC, via the Research Centre for Non-Destructive Evaluation RCNDE, and Rolls-Royce plc.

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Experimental Validation of an Eddy Current Probe for Defect Detection in Thick Conducting Specimen

---**Mahesh Raja P**[1], Kavitha Arunachalam[2], [3]Krishnan Balasubramanian[3], [1, 2]Department of Engineering Design, [3]Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India-600036

---Eddy current testing (ECT) is a widely used non-destructive evaluation (NDE) technique to detect surface and subsurface cracks in thin conducting specimen typically less than 6 mm. This paper deals with numerical modeling and experimental validation of an eddy current probe for detecting subsurface cracks in thick conducting specimen of 10 to 15 mm thickness. Numerical modeling was done using finite element method (FEM) based simulation software, COMSOL Multiphysics® for a pancake type coil above a 15 mm thick conducting plate with 30 MS/m electrical conductivity. Coil parameters namely inner radius (r_1), outer radius (r_2), number of turns (N), height (L), and operating frequency (f) were optimized for deeper penetration of the magnetic flux density in the conducting plate. The optimized coil was fabricated using 38 gauge copper wire and impedance measurements were acquired on a 10 mm thick aluminum plate with 0.5 mm wide and 1.8 mm deep notch fabricated using electrical discharge machining (EDM) process. Measurements were recorded over 300 Hz – 1000 Hz using a two axis scanner with 1 mm spatial resolution for surface and subsurface defect detection by flipping the aluminum plate. The coil inductance in air and above the conducting plate was 2.73 mH and 2.33 mH respectively. Change in coil inductance, $|\Delta X/X_0|$ was 15e-3 at 1000 Hz and 0.8e-3 at 450 Hz for surface and subsurface defects respectively. Absolute coil measurements were in good agreement with simulations and indicate the ability to detect surface as well as the subsurface EDM notch. Preliminary results further indicate that signal sensitivity is lower for the subsurface defect which could be improved using giant magneto resistive (GMR) sensor.

2:10 PM

Limitations of Eddy Current Testing in a Fast Reactor Environment

---**John Bowler**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---The feasibility of using eddy current probes for detecting flaws in a fast reactor structures has been investigated. The primary requirement is to design probes and optimize their performance for the detection of flaws immersed in high temperature liquid metal in order to ensure the safe operation of the reactor. With these objectives in view, a parametric study has been carried out to evaluate the variation in probe performance as their parameters are changed, taking into account the effects of immersion in conductive coolant. In parallel with the work on eddy current probe optimization, we have designed a three axis scanning system to acquire eddy current data automatically in a liquid metal and used the data to validate simulations.---This work is funded by the Department of Energy under Award DE-NE0000676 and performed at Iowa State University

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Model-Based Inverse Methods for Sizing Cracks of Varying Shape and Location in Bolt-Holt Eddy Current (BHEC) Inspections

---John C. Aldrin, Computational Tools, Gurnee, IL, 60031; Harold A. Sabbagh, Liming Zhao, Elias Sabbagh, R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Mark Keiser, Jennifer Flores-Lamb, David S. Forsyth, TRI/Austin, Austin, TX 78746; Eric A. Lindgren and Ryan Mooers, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---As maintenance of structural components of aircraft moves from time-based maintenance to condition-based maintenance, there is a need for innovative methods to not simply detect damage but to completely characterize their state. This paper presents work on enhancing flaw characterization capability for bolt hole eddy current (BHEC) techniques. A comprehensive approach is presented to perform model-based inversion of crack characteristics using eddy current techniques. This process includes fast forward models, a robust noise removal process, the use of feature extraction to minimize inversion problem complexity, a model calibration and verification process, a multi-stage inverse method parameter estimation technique, and a software environment to facilitate inversion applications. Progress has been made on a demonstration of using model-based inverse methods of crack characterization using a BHEC nondestructive evaluation technique. Data was acquired from both standard eddy current hardware and a prototype BHEC system with z-axis position encoding for 100+ crack specimens. The test specimens included a wide range of crack sizes and shapes, including mid-bore, corner and through-thickness crack types (see Figure 1). Signal processing algorithms were developed to process and extract features from the 2D data sets, and inversion algorithms using VIC-3D generated surrogate models were implemented. New model results are presented which now better address the effect of having a corner crack at an edge and a through crack adjacent to two edges. A two-step inversion process was implemented that first evaluates the material layer thickness, crack type and location, in order to select the most appropriate VIC-3D surrogate model for crack sizing. The final step in the inversion process is simultaneously evaluating crack depth, length and width (opening) for the eddy current signal. Inversion results for select crack data are presented with trends in the experimental response for varying crack location and size. Sizing performance was found to depend on the size and location of the flaw.

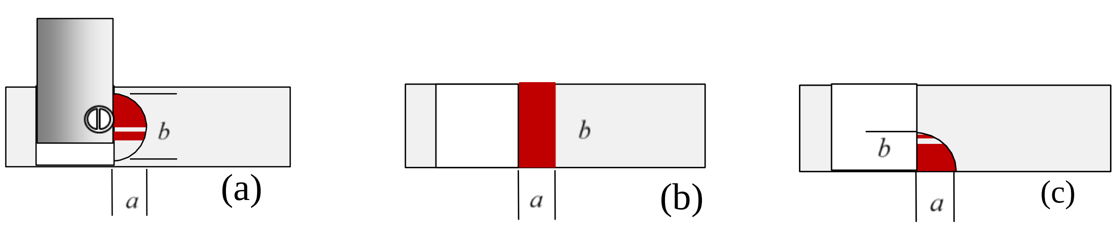

Figure 1. BHEC inversion problems: (a) mid-bore, (b) through and (c) corner crack characterization.

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Numerical Modeling of Eddy Current Testing of U-Shaped Tubes by Differential Geometry

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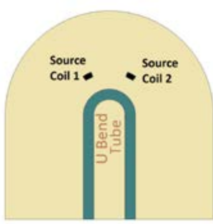
---U-bend sections are common and critical parts of the tubes in steam generators of nuclear power plants. The curved section poses some challenges during Eddy Current Testing (ECT) because of the “complex” trajectory of the probe. From the numerical point of view, modelling in an efficient and accurate manner such ECT inspection configurations could be nontrivial. As a matter of fact, the lift-off distance between the probe and tube wall is usually very small. Therefore, a very fine mesh is required, especially near the probe region, to keep the geometric discretization error within a tolerance suitable to accurately describe the eddy current field. This results in more computational resource consumption and prolonged computational time. It is known from long time that Maxwell equations are co-variant with respect to change of coordinates [1, 2], i.e. regardless the actual system of coordinates the equations remain unaltered in their form. This is possible when the electric and magnetic fields are represented in the proper components (tensor densities). A change of coordinates results only in a proper change of material properties [1-3]. The co-variant nature of Maxwell equations can be exploited to circumvent the issues related to numerical modelling of ECT of U-bend tubes. A possible strategy consists in a proper change of spatial coordinates for transforming the curved U-bend tube into a straight structure and for increasing the lift-off, thus reducing the intrinsic complexity of the problem (Fig. 1).



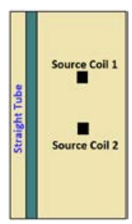


Figure 1. Geometry of the U-bend tube in the Cartesian frame (left) and the same problem after a proper change of (spatial) variables (right).

In this contribution, the proposed approach will be shown for simulating eddy current distribution within a U-bend tube. Preliminary numerical examples will refer to a 2D configuration. Cross-validation between the computations carried out using the standard Cartesian coordinates and the “new” ad-hoc coordinates will be presented.

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Numerical Simulation in ACFM Inducer Design

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---Inducer design plays an important part in Alternating Current Field Measurement (ACFM). It involves influence analysis of some key parameters on the perturbation of the magnetic field above the crack. Experimental analysis methods are time-consuming, high cost and have experimental errors. Finite element method (FEM) can overcome these shortcomings, and is adopted in this paper to aid design of ACFM inducer. Two kinds of ACFM Inducer, twin coil and U-shaped inducer are proposed, and corresponding numerical simulation models are built. In the model for the U-shaped inducer, the inducer comprises a U-shaped core and a current-carrying coil. The specimen is modeled by a plate, and the surface breaking crack in the specimen is modeled by a semi-ellipse [1], as shown in Figure 1. The models are then verified by comparison with experimental data. After that, influence of various parameters, such as core material, core dimensions and inducer lift-off on the perturbed magnetic field above the crack is analyzed in the models and suggested parameters are given based on the influence analysis results. The numerical simulation results provide guidance to design of ACFM inducer.**---**This work was supported by National Natural Science Foundation of China (51404283), PetroChina Innovation Foundation (2014D-5006-0602) and Science Foundation of China University of Petroleum, Beijing (YJRC-2013-47).

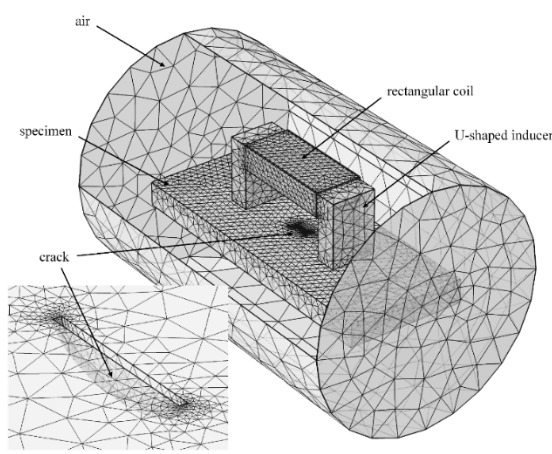

Figure 1. Numerical simulation model of the U-shaped inducer.

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Characterising Surface Features on Conducting Specimens Through an Insulation Layer Using Capacitive Imaging Technique

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---Capacitive imaging (CI) technique is a novel electromagnetic NDE technique. It uses a carefully designed probe with a pair of metal electrodes. Interaction between the Quasi-static electromagnetic field from the electrode pair and the testing material causes changes in signal when the electrical properties of the sample themselves change, leading to the possibility of imaging. Due to its capacitive nature, the CI technique requires single side non-contact access to the testing material and little sample surface preparation. In addition, it provides a very clear and simple defect indication. Previous work [1] has demonstrated the feasibility of the CI technique to the detection of surface features on conducting specimens. It is found that the CI technique is useful to confirm the presence of a defect but cannot further characterise it due to the “blurring effect”. The problem caused by the blurring effect is more significant, when trying to image smaller feature though a thicker insulation layer (comparing to the dimensions of the CI probe). This paper aims to tackle this problem using a two dimensional deconvolution method based on the analysis of the measurement sensitivity distribution. In this paper, the trade-offs between penetration depth, signal strength and imaging resolution of the CI technique are discussed. The blurring effect due to the CI probe geometry is explained. The proposed method to retrieve the real shape of the feature is then described in details, and its feasibility is also demonstrated. The results indicated that the CI technique could be useful to detect Corrosion Under Insulation (CUI).---This work was supported by the Natural Science Foundation of China (No. 51205412), the China Postdoctoral Science Foundation (No. 2013M540568 and No. 2014T70666), the Scientific and Technological Developing Project of Shandong province (No.2013GHY11513).

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Monotonicity of Time-Constants and Real-Time Imaging in Eddy Current Testing

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---Eddy current testing (ECT) is a widely used non-destructive evaluation (NDE) technology in detecting flaws in conducting materials [1]. In a typical ECT system, a primary time-varying magnetic flux density is applied to a conducting specimen Ω from outside and induces eddy currents inside the conductor. Any defects and/or conductivity discontinuities in the specimen change the eddy current pattern and hence affect the total (primary plus reaction) magnetic flux density. The measurements, usually collected from external field sensors or pick-up coils, are processed to detect the presence of defects or even to reconstruct the defect shapes. Defect profile detection and or imaging is a very crucial part of eddy current testing. It helps to further evaluate the frangibility and residual life of the objects and effectually avoiding risks from structural failures. ECT is applied to important industrial areas such as the testing of steam generating pipelines in power plants, gas and oil pipelines, multi-layered aircraft structures, etc. From a general perspective, imaging methods are categorized as iterative methods and non-iterative methods. Iterative methods are widely applied. Their drawback is the high computation and time cost since they require the solution of at least one forward problem in each iteration, which is a computational intensive task. On the opposite, non-iterative methods address the problem from a totally different point of view: they estimate if a given voxel of the specimen is part or not of the unknown defect, by means of a local test which is independent from other voxels. Monotonicity based imaging methods have been proposed in electric resistance tomography [2], eddy current testing in large skin-depth regime [3] and small skin-depth regime [4]. In [5] an experimental validation was presented. In this paper we propose a monotonicity property in time domain which is valid for arbitrary regimes in eddy current testing [6, 7]. Moreover, an inversion algorithm based on this property is presented and validated by means of numerical examples.

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3-D Finite Element Modelling of Eddy Current Inspection of Surface EDM Notches Using a Reflection Differential Split-D Probe

---**Ehsan Mohseni**[1], Demartonne Ramos França[1], Martin Viens[1], Wen Fang Xie[2], Baoguang Xu[2]
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---Employing eddy current (EC) differential sensors for scanning shallow surface cracks has been increasing significantly over the last decade considering the insensitivity of these sensors to gradual variations in thickness, conductivity and permeability of the components under test. Among various differential sensors, the reflection differential split-D pencil probes are of interest to detect tiny surface cracks because of their relatively small footprint. Recent researches on split-D probes are mostly focused on design optimization since the slightest modification in configuration could considerably affect their functionality [1]. The present study, however, pursues a different objective mostly concerning the application of split-D probes for crack characterization. In particular, the reliability of 3-D finite element modelling (FEM) of split-D probes is investigated to assess the relationship between the notch depths and the corresponding signal. Hence, the computed signals for various notch depths could be used further for sizing purposes through training of artificial intelligent inversion algorithms [2]. For this end, COMSOL Multiphysics is used to establish a 3-D FEM of the interaction between a split-D probe and surface electrical discharge machined (EDM) notches in aluminum (figure 1b). Specifying the FEM parameters for the geometry of split-D probes is very challenging due to its modelling complexities. In order to attain a better understanding of parameters set up in COMSOL, the simpler case of a multi-turn cylindrical absolute coil is modeled in 3-D first (Figure 1a). The FEM results for the absolute coil scanning over a surface notch are validated with existing theoretical and experimental impedance data. The effect of simulation parameters (*e.g.* geometry definition, mesh size and distribution, applied physics, and solvers) is investigated for 3-D modelling of both absolute and differential probes to achieve FEM results with higher accuracy. In the second part of the study, the behaviour of signal variations as a result of changes in notch depth is studied for further sizing purposes. Accordingly, a split-D probe is modeled in 3-D and simulations are performed for scanning EDM notches with different depths over a frequency range extending from 500 kHz up to 3 MHz. The results are then compared to experimental measurements in terms of probe impedance variations according to operating frequencies.---This research is mainly funded by Natural Sciences and Engineering Research Council of Canada (NSERC). The authors would like to acknowledge the CMC microsystems for providing access to computer aided design (CAD) software.

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In-Situ Calibration of Pulsed Eddy Current Detection of Cracks at Fasteners in CP-140 Aircraft

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---Previously, it has been shown that pulsed eddy current (PEC) can successfully detect cracks as small as 0.030” (1.2 mm) in the second layer of aluminum wing structures around ferrous fasteners in CP-140 aircraft (P3-Orion airframe). The basic approach is to use principal components analysis (PCA) to reduce the signal to a small number of scores. A cluster of PCA scores from fasteners without associated cracks is defined. Using the Mahalanobis distance (measure of distance in standard deviations), signals more than a critical distance away from the cluster center are called “cracks”. Unfortunately, the technique is sensitive to a number of parameters such as first layer thickness, Al conductivity and fastener permeability. This makes coming up with a calibration block to cover the variable inspection conditions challenging. Under the assumption that the relative number of cracked sites is small, robust statistics provides a means to develop a calibration on-the-fly using the piece under test and no a priori knowledge about which fasteners have defects (cracks). This technique is shown here to work almost as well as the case where there is complete a priori knowledge of the test specimen. The approach can be generalized to almost any situation in which the assumption of a low density of defects is valid. In addition, the statistical modelling approach that is used can help generate a POD in situations where objective criteria, as applied in automated NDT analyses, for example, are used to determine the presence of defects.

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---Surface Crack Detection for Polycrystalline Diamond Compact Bit Using Pulsed Eddy Current Thermography

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---Polycrystalline diamond compact (PDC) bit are one of most common drill bits used in petroleum drilling industry. Crack which often occurs on the surface of PDC bit is the main type of defects in the process of employment, and most reasons leading to this crack are rock collision and fatigue, etc. The sizes of the crack often are very small (shown as Fig.1), which makes it difficult for observation and detection. As a new infrared thermography technique, pulsed eddy current thermography (PECT) is powerful to detect the surface crack on PDC bit, in which the temperature field is excited by the eddy current and the surface crack can be detected over a relatively wide area within a short time. In this paper, PECT is used to detect two fatigue cracks on two different PDC bits retiring from oil drilling field and the influence of excitation time on the detection result for the cracks will be investigated. In addition, principal component analysis (PCA) and discrete Fourier transform (DFT) are used for processing the acquired thermography sequences from the experiments to improve the detection sensitivity of the cracks. Based on the experimental results, optimum excitation time and proper thermal image processing method are given for the surface crack on PDC bit. To sum up, PECT has the potential to be a new nondestructive detection method for the surface crack on PDC bit.

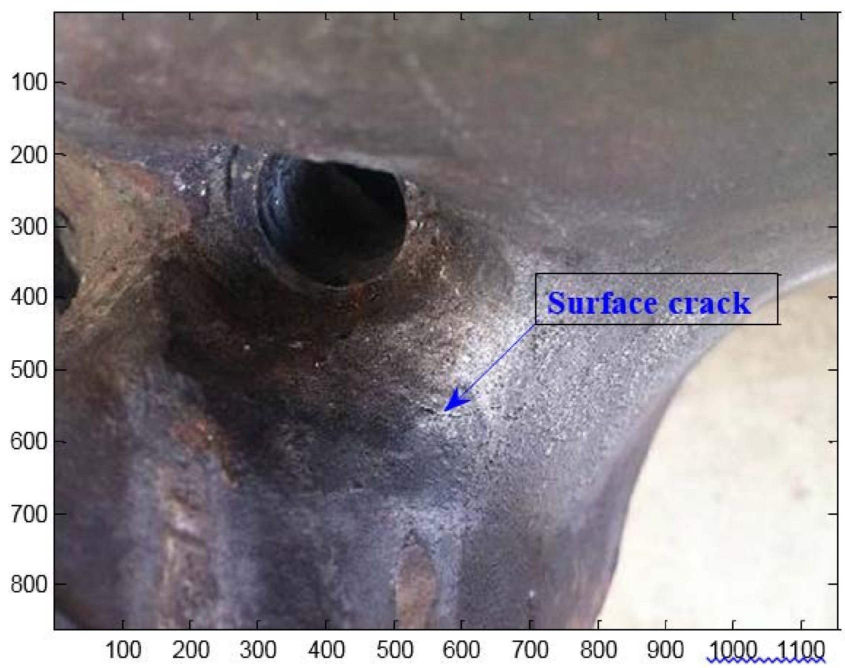

Figure 1. The photo of one surface crack on PDC bit

Session 6

SESSION 6
6th EAW
Lakeshore A

INTRODUCTION TO THE 6TH EAW
Eric Lindgren and Uwe Ewert, Co-Chairpersons

1:30 PM **Holistic Assessment of the Reliability of NDE: Novel Insight on Influencing factors on POD and Human Factors**
---**Christina Müller**[1], Marija Bertovic[1], Daniel Kanzler[1], Mato Pavlovic[2], Martina Rosenthal[1], Ralf Holstein[2], Andrea Gianneo[4], and Ulf Ronneteg[3;] [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany; [2]DGZfP Ausbildung und Training GmbH. Berlin, Germany; [3]SKB Swedish Nuclear Fuel and Waste Management Co., Oskarshamn, Sweden, [4]Politecnico Milano, Italy

2:05 PM **Living Reliability in Industry**
---**Greg Selby**, Electric Power Research Institute, 1300 West W. T. Harris Boulevard, Charlotte, NC 28262

2:40 PM **How NDT is Organized - Influence on the Reliability of NDE**
---**Ralf Holstein**[1] and Christina Müller[2], [1]DGZfP Ausbildung und Training GmbH. Berlin, Germany; [2]BAM Federal Institute for Materials Research and Testing, Berlin, Germany

3:10 PM ***Break***

RELIABILITY OF SHM
David Forsyth and Bernd Koehler, Co-Chairpersons

3:30 PM **SHM Reliability and Implementation Overview – A Personal Military Aviation Perspective**
---**Eric Lindgren**, USAF, AFRL/RXCA, Wright Patterson AFB, Dayton OH, 937-255-6994

4:10 PM **Best Practices for Evaluating the Capability of Nondestructive Evaluation (NDE) and Structural Health Monitoring (SHM) Techniques for Damage Characterization**
---**John C. Aldrin**[2], Charles Annis[3], Eric A. Lindgren[1], and Harold A. Sabbagh[4], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Computational Tools, Gurnee, Illinois, 60031; [3]Statistical Engineering, Palm Beach Garden, FL; [4]Victor Technologies LLC, Bloomington, IN 47401

4:50 PM **Structural Health Monitoring Ultrasonic Thickness Measurement Accuracy and Reliability of Various Time-of-Flight Calculation Methods**
---**Thomas J. Eason**[1,2], Leonard J. Bond[1], Mark G. Lozev[2], [1]Center for Nondestructive Evaluation, Iowa State University, 1915 Scholl Rd., Ames, IA; [2]BP Products North America, Refining & Logistics Technology, 150 W. Warrenville Rd., Naperville, IL 60563

5:10 PM **Structural Health Monitoring and Probability of Detection Estimation**
---**David Forsyth**, TRI/Austin, 9225 Bee Caves Road, Austin, TX 78733

1:30 PM

Holistic Assessment of the Reliability of NDE: Novel Insight on Influencing factors on POD and Human Factors

---**Christina Müller**[1], Marija Bertovic[1], Daniel Kanzler[1], Mato Pavlovic[2], Martina Rosenthal[1], Ralf Holstein[2], Andrea Gianneo[4], Ulf Ronneteg[3;] [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany; [2]DGZfP Ausbildung und Training GmbH. Berlin, Germany; [3]SKB Swedish Nuclear Fuel and Waste Management Co., Oskarshamn, Sweden, [4]Politecnico Milano, Italy

---After summarizing the essences of the past workshops the paper will give an overview of new methodologies for evaluating the reliability of NDE systems. The aim is to evaluate the reliability accurately, reliably and efficiently, in accordance with the specific requirements of industrial application taking into account the very different nature of influencing factors. Using the Modular Reliability Model the three different main influencing elements, i.e. intrinsic capability (IC), application parameters (AP) and the human factors (HF), are, in the first instance, investigated separately. The intrinsic capability stands for the pure physical-technological process of the signal detection caused by the waves or the rays from a material defect in the presence of noise (caused by the material and the devices). This intrinsic capability is the upper bound of the possible reliability. Already when measuring this intrinsic capability for thick walled components the original one-parameter POD should be extended to a multi-parameter POD, where, in addition to the defect size, a number of additional physical parameters, such as the grain size distribution (or attenuation), defect depth, and angle or surface roughness, must be considered. For real life cycle assessments it is necessary to evaluate the signal response from real defects. The industrial application factors, e.g. coupling conditions, limited accessibility, heat and environmental vibrations, diminish the reliability. The amount of reduction can be determined quantitatively, if the underlying conditions are controlled. In case they are not controlled it is necessary to count for a fluctuation in the reliability in the field anyway. The third group of important influencing factors are the human factors, which do not only cover the individual performance capability of the inspectors but also the design of the working place, the procedure, the teamwork quality, interaction with systems, the organization, and finally, the relationship between the companies involved in the inspection process and to which extend the responsible parties are aware of it. When comparing an “ideal inspection” with a “real inspection” it is worthwhile to look at the existing practices, rules and standards. How do they really support reliable testing? With respect to the industrial end user, it needs to be shown how the level of reliability of NDE, influenced by the different factors, has an impact on acceptance or rejection of safety critical parts. The holistic approach will be illustrated by examples of the reliability investigation of the inspection of copper canisters for nuclear fuel deposit in Sweden and Finland.

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Living Reliability in Industry

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Reliability is always in the first tier of considerations for NDE in industry. However, reliability costs money and effort. In order to improve reliability we face two hurdles: obtaining management cognizance that committing money to reliability is a wise expenditure, and obtaining management and worker commitment to spending the time and effort to take the steps that will improve reliability. We commonly make these commitments easier by mandating the steps and turning reliability into a matter of compliance. This works, but it would be better to create a culture of passion for reliability in NDE. Easy to say.

As researchers we can foster this passion by developing technologies that make the worker's time in the plant environment more productive and safer, in addition to improving the reliability of the NDE result. For example, wearable technologies can present more information to the examiner while keeping his hands free. Probe tracking technologies can increase the scope of examinations in which the data is recorded in sufficient detail to permit meaningful offline analysis, shortening the scanning time. Machine learning software, and more importantly the rapidly improving power of compact computing platforms, could aid in interpretation of the data both in real time and in offline analysis.

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How NDT is organized - Influence on the Reliability of NDE:

Ralf HOLSTEIN [1] Christina MÜLLER [2], [1] DGZfP Ausbildung und Training GmbH. Berlin, Germany, [2] BAM Federal Institute for Materials Research and Testing, Berlin, Germany

--Non-destructive testing is not only performed in a perfect laboratory environment. It is mostly part of a fast industrial process, embedded in a social, commercial and organizational environment. This environment with its culture, values and rules is influencing the behaviour of people – it seems logical that is influencing the reliability of NDT as well. Starting point of this paper is the lecture “NDT Reliability in the Organizational Context of Service Inspection Companies“, presented during the 5th European American Workshop in Berlin. The content of an “organizational factor” as defined by Dr. Fahlbruch in the EAW 2009 has been analysed. An inner process and a process environment have been drafted and discussed. A survey within German service inspection companies was performed in 2014 to study their situation and to analyze organizational influences during their work. A significant number of companies answered the questionnaire, the outcome about the conditions during their daily work was interesting. So it was found, that level-2-personnel is key for daily operations, and that gaining necessary information’s regarding NDT-requirements from the customer is often a large challenge. The results have been used to form a clearer picture of the organizational influences and to modify the picture of organizational influences. The part of the model regarding the internal influence was proved and filled with typical content (Figure 1).

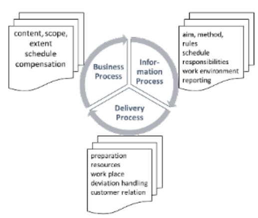

Figure 1 Content of the internal factors

The process environment have been renamed in to “external organizational factors”. Each part was checked on the real conditions in practice and could be proved.

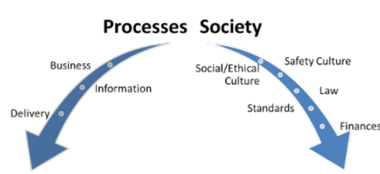

Figure 2 Overview of the factors

It will support the understanding of those factors to build an organizational ground for a reliable NDT.

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SHM Reliability and Implementation Overview – A Personal Military Aviation Perspective
---**Eric Lindgren**, USAF, AFRL/RXCA, Wright Patterson AFB, Dayton OH, 937-255-6994,

---Structural Health Monitoring has been proposed as a technical solution to address the needs of military aviation to address the time and cost to perform nondestructive inspections. While the potential to realize significant benefits to military aviation, there are some additional considerations that have to be addressed before such systems can be integrated into military platforms. Some considerations are pervasive to all aviation, such as how to assess the reliability and reproducible capability of these systems. However, there are other considerations that are unique to military aviation that still need to be addressed before these types of systems can be used. The intent of this presentation and paper is complement the review of the outcome of the SAE G-11 SHM committee special workshop on SHM reliability in April of 2015 to touch on the parameters that are different from the general perspective of commercial aviation. The material addresses differences that include general approaches to manage the integrity (i.e. safety) of aircraft, frequency of use, design differences, various maintenance practices, and additional descriptions addressing differences in the execution of inspections. The objective of this presentation to improve the awareness of the research and development community of the different and unique requirements found in military aviation, including the differences between countries, services, and aircraft type. This information should provide additional information to assist the research and development community to tackle the challenges that occur when exploring how to address the needs of military aviation. It is not intended to be comprehensive overview of all stakeholders' perspectives, but to serve as a launch point for additional discussion and exploration to formulate opportunities to address the needs of military services and realize the potential of Structural Health Monitoring to assist in the management of military aviation assets.

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Best Practices for Evaluating the Capability of Nondestructive Evaluation (NDE) and Structural Health Monitoring (SHM) Techniques for Damage Characterization

---**John C. Aldrin**[2], Charles Annis[3], Eric A. Lindgren[1], Harold A. Sabbagh[4], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Computational Tools, Gurnee, Illinois, 60031; [3]Statistical Engineering, Palm Beach Garden, FL; [4]Victor Technologies LLC, Bloomington, IN 47401

---There have been some past efforts to define and demonstrate a complete process for evaluating sizing capability, specifically addressing discontinuities in welds and corrosion in aircraft structures. However, there are some outstanding issues with the current practice. One metric frequently cited is the calculation of the 95% safety limit against undersizing bound for quantifying sizing performance for discontinuities in welds. However, there are some important assumptions, such as linearity in the response and constant variance with changes in flaw size that must be addressed before using this measure. From the perspective of quantifying the reliability of NDE and SHM systems, one must evaluate the relationship between the accuracy in estimating the damage or material state estimates (â) with respect to the actual condition (a). An evaluation of the characterization error (CE), ê = â - a, with predication bounds for all critical location and sizing estimates is considered necessary. Since this evaluation is generally similar to the current procedure for POD evaluation relating an NDE measurement (â) and a critical flaw size (a), the proposed foundation for the experimental-based CE procedure will be MIL-HDBK-1823A [1]. A comprehensive approach to NDE and SHM characterization error (CE) evaluation is presented that follows the framework of the 'ahat-versus-a' regression analysis for POD assessment [2]. A key point is that reliability evaluation is likely more complex with respect to current POD evaluations and indicates the importance of engineering and statistical expertise in the model-building process to ensure all key effects and interactions are addressed [3]. As with any POD evaluation study, it is important to plot the data and determine the best statistical model to apply to the evaluation. For example, it is important to verify the presence and frequency of several possible classes of poor characterization results due to: weak signals, saturated signals, and/or ill-posed inverse problems. Justifying the statistical model choice and assumptions are key. In this paper, several sizing case studies are presented with detailed evaluations of the most appropriate statistical model for each data set. A discussion is included on how to consider statistical model error prediction bound with respect to existing sizing claims. Lastly, a discussion is presented on the use of a model-assisted approach to assess the reliability of NDE and SHM characterization capability. Best practices of using models are presented for both an eddy current NDE sizing [2] and vibration-based SHM case studies [4]. The results of these studies highlight the general protocol feasibility, emphasize the importance of evaluating key application characteristics prior to the study, and demonstrate an approach to quantify the role of varying SHM sensor durability and environmental conditions on characterization performance.

References:

1. U.S. Department of Defense, Handbook, Nondestructive Evaluation System Reliability Assessment, MIL-HDBK-1823A, 7 (April 2009).
2. Aldrin, J. C., Annis, C., Sabbagh, H. A., Knopp, J., and Lindgren, E. A., "Assessing the Reliability of Nondestructive Evaluation Methods for Damage Characterization," Review of Progress in QNDE, Vol. 33, AIP, pp. 2071-2080, (2014).
3. Annis, C., Aldrin, J. C., and Sabbagh, H. A., "What is Missing in Nondestructive Testing Capability Evaluation?" Materials Evaluation, Vol. 73, n 1, pp. 44-54, (2015).
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5:10 PM

Structural Health Monitoring and Probability of Detection Estimation

David S. Forsyth, TRI/Austin, 9225 Bee Caves Road, Austin, TX , USA 78733

--Structural health monitoring (SHM) methods are often based on nondestructive testing (NDT) sensors and are often proposed as replacements for NDT to lower cost and/or improve reliability. In order to take advantage of SHM for life cycle management, it is necessary to determine the Probability of Detection (POD) of the SHM system just as for traditional NDT to ensure that the required level of safety is maintained.

Many different possibilities exist for SHM systems, but one of the attractive features of SHM versus NDT is the ability to take measurements very simply after the SHM system is installed. Using a simple statistical model of POD, some authors have proposed that very high rates of SHM system data sampling can result in high effective POD even in situations where an individual test has low POD.

In this paper, we discuss the theoretical basis for determining the effect of repeated inspections, and examine data from SHM experiments against this framework to show how the effective POD from multiple tests can be estimated.

TUESDAY

TUESDAY, JULY 28, 2015

	Session 7 Guided Waves II ***Nicollet D1***	**Session 8 Additive Manufacturing** ***Nicollet D2***	**Session 9 UT Fundamentals and Composites** ***Nicollet D3***	**Session 10 6th EAW Advanced Methods** ***Lakeshore A***	
8:30 AM					
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10:10	COFFEE BREAK				
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12:10 PM	LUNCH				

Session 11 – STUDENT POSTERS – 1:30 – 3:10 PM – *Nicollet AB*

	Session 12 NDE in the Railway Branch ***Nicollet D1***	**Session 13 Microwave, Terahertz and Infrared NDE** ***Lakeshore C***	**Session 14 Eddy Current I** ***Nicollet D3***	**Session 15 6th EAW Application in Industry** ***Lakeshore A***	**Session 16 Composites I** ***Nicollet D2***
3:10	COFFEE BREAK				
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Session 7

SESSION 7

GUIDED WAVES II

Peter Cawley and Ronald A. Roberts, Co-Chairpersons

Nicollet D1

8:30 AM **Noncontact Excitation of Guided Waves (A_0 Mode) Using an Electromagnetic Acoustic Transducer (EMAT)**
---**P. Fromme**, Department of Mechanical Engineering, University College London, Torrington Place, London, WC1E 7JE, United Kingdom

8:50 AM **Dispersive Matched Filtering of Ultrasonic Guided Waves for Improved Sparse Array Damage Localization**
---Gregory C. Luppescu, Alexander J. Dawson, and **Jennifer E. Michaels**, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

9:10 AM **Multidimensional Guided Wave Dispersion Recovery for Locating Defects in Composite Materials**
---**Joel B. Harley**[1] and Luca De Marchi[2], [1]Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112; [2]Department of Electronics, Computer Sciences and Systems (DEIS), University of Bologna, Bologna, Italy

9:30 AM **Development of an Omnidirectional SH_0 Piezoceramic Transducer**
---**Pierre Belanger** and Guillaume Boivin, Département de Génie Mécanique, École de Technologie Supérieure, 1100 rue Notre-Dame Quest, Montréal (Québec), H3C 1K3, Canada

9:50 AM **A PVDF Array Sensor for Lamb Wave Reception for Aircraft SHM**
---**Baiyang Ren** and Cliff Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA, 16802

10:10 AM ***Break***

10:30 AM **Wave Mode Extraction from Multimodal Guided Wave Signal in a Plate**
---**Madis Ratassepp** and Zheng Fan, Nanyang Technological University, School of Mechanical and Aerospace Engineering, 50 Nanyang Avenue, Singapore 639798

10:50 AM **Defect Depth Sizing Using Guided Waves**
---**Adam C. Cobb** and Jay L. Fisher, Sensor Systems and NDE Technology Department, Southwest Research Institute, San Antonio, TX 78228

11:10 AM **Monitoring Thicknesses Along a Line Using Guided Waves**
---**R. Howard** and F. Cegla, NDE Group, Imperial College London, Exhibition Road, South Kensington SW7 2AZ, United Kingdom

11:30 AM **Practical Ultrasonic Damage Detection on Pipelines Using Component Analysis Methods**
---**Chang Liu**, Jacob Dobson, and Peter Cawley, Imperial College, 310A City & Guilds Building, Exhibition Road, London SW7 2AZ, United Kingdom

11:50 AM **Investigation on Empowering One Direction Emission of Guided Waves to Avoid Undesired Reflections from Other Pipe Attachments.**
---**Peter W. Tse** and Fang Zhou, The Smart Engineering Asset Management Laboratory (SEAM) and The Croucher Optical Nondestructive Testing Laboratory (CNDT), Department of Systems Engineering & Engineering Management, City University of Hong Kong, Hong Kong, China

12:10 PM ***Lunch***

8:30 AM

Noncontact Excitation of Guided Waves (A_0 Mode) Using an Electromagnetic Acoustic Transducer (EMAT)

---**P. Fromme**, Department of Mechanical Engineering, University College London, Torrington Place, London, WC1E 7JE, United Kingdom

---Fatigue damage can develop in aircraft structures at locations of stress concentration, such as fasteners, and has to be detected before reaching a critical size to ensure safe aircraft operation. Guided ultrasonic waves offer an efficient method for the detection and characterization of such defects in large aerospace structures. Electromagnetic acoustic transducers (EMAT) for the noncontact excitation of guided ultrasonic waves were developed. The transducer development for the specific excitation of the A_0 Lamb wave mode with an out-of-plane Lorentz force is explained. The achieved transfer function and angular dependency of the excited guided wave pulses were measured using a noncontact laser interferometer. Based on the induced eddy currents in the plate a theoretical model was developed and reasonably good agreement with the measured transducer performance was achieved. The application of the developed transducers for defect detection in aluminum components using fully noncontact guided wave measurements was demonstrated. Excitation of the A_0 Lamb wave mode was achieved using the developed EMAT transducer and the guided wave propagation and scattering was measured using a noncontact laser interferometer.

8:50 AM

Dispersive Matched Filtering of Ultrasonic Guided Waves for Improved Sparse Array Damage Localization

---Gregory C. Luppescu, Alexander J. Dawson, and **Jennifer E. Michaels**, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

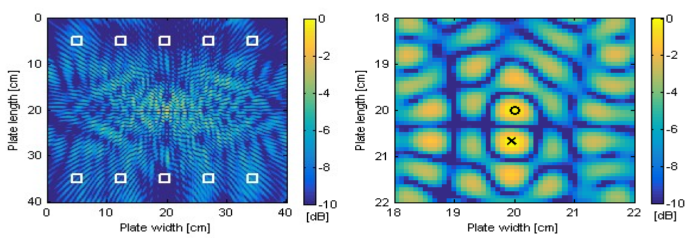
---Although bulk waves have served as the industry standard in nondestructive evaluation for many years, guided waves (Lamb waves in plates) have become the focus of many current research efforts because they are able to interrogate larger areas of a structure in a shorter period of time. Despite this advantage, guided waves also have characteristics that obfuscate data interpretation. The first property of guided waves that complicates analysis is their dispersive nature: their wave speed is a function of frequency. The second is that they are multimodal: they propagate as multiple symmetric and antisymmetric modes. Using pulse-compression techniques and *a priori* calculations of theoretical dispersion curves, the dispersive matched filter attempts to take advantage of these otherwise undesirable characteristics by maximizing the autocorrelation for only one mode, ideally increasing both the signal-to-noise ratio and time-resolution of ultrasonic guided wave measurements used for NDE. In this research, the responses from broadband chirp excitations are recorded from a sparse transducer array after propagation through an aluminum plate containing no damage, simulated damage, through-holes, and cracks. Dispersive matched filtering is applied to the measurements and localization images are generated using the delay-and-sum method. Imaging results are compared to those obtained with narrowband tone burst excitations in terms of their ability to detect and localize the different scatterers.---This work was partially funded by the National Aeronautics and Space Administration under Grant No. NNX12AL13A (Dr. Cara Leckey, Program Manager). The authors also gratefully acknowledge the support of the Raytheon Company to the Opportunity Research Scholars program at the Georgia Institute of Technology.

9:10 AM

Multidimensional Guided Wave Dispersion Recovery for Locating Defects in Composite Materials

---**Joel B. Harley**[1] and Luca De Marchi[2], [1]Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112; [2]Department of Electronics, Computer Sciences and Systems (DEIS), University of Bologna, Bologna, Italy

---In recent years, the use of fiber reinforced composites in newly manufactured aerospace and civil structures has grown at a rapid rate. Compared with traditional metals, composites offer the advantage of greater strength, greater flexibility, and lighter weight. Yet, ensuring the structural health and integrity of composite structures is a significant challenge. Defects in composite materials are difficult to detect by visual inspection and with traditional nondestructive testing methods. Ultrasonic guided waves have shown significant promise for detecting composite defects. Yet for composites materials, guided wave methods are often limited by complex and unknown wave propagation characteristics. Wave propagation characteristics vary as a function of propagation direction and these characteristics vary significantly with the manufacturing process. As a result, there is a significant need for methods that can estimate the direction-dependent characteristics of a composite structure and use these estimates to detect and locate defects. In this paper, we address this need by adapting prior work on sparse wavenumber analysis [1] and data-driven matched field processing [2]. We use sparse wavenumber analysis to recover the multidimensional dispersion curves of a composite plate. We then integrate the multidimensional dispersion curves with data-driven matched field processing to locate the defect. We experimentally demonstrate this approach by utilizing guided wave measurements from a scanning laser doppler vibrometer to locate an acoustic source in the center of a unidirectional, fiberglass composite plate. Figure 1(a) illustrates the resulting image across the plate and Figure 1(b) illustrates the image near the source location. The white squares denote 10 measurement locations, the black circle denotes the true location of the source, and the black cross represents the estimated location the source (i.e., the image's maximum value). The distance error is 0.6726 cm. These results illustrate that we can achieve high localization accuracy with relatively few sensors. In the paper, we further describe how our method is implemented and then compare it with other guided wave approaches.



(a) (b)

Figure 1. Localization results (a) across the entire plate and (b) around the acoustic source on a undirectional fiberglass plate. The white squares represent locations of each measurements used, the black circle represents the true source location, and the black cross represents the estimated location.

References:

1. J. B. Harley and J. M. F. Moura, "Sparse recovery of the multimodal and dispersive characteristics of Lamb waves," *J. Acoust. Soc. Am.*, vol. 133, no. 5, pp. 2732–2745, May 2013.
2. "Data-driven matched field processing for Lamb wave structural health monitoring." *J. Acoust. Soc. Am.*, vol. 135, no. 3, pp. 1231–1244, Mar. 2014.

9:30 AM

Development of an Omnidirectional SH0 Piezoceramic Transducer

---**Pierre Belanger** and Guillaume Boivin, Département de Génie Mécanique, École de Technologie Supérieure, 1100 rue Notre-Dame Ouest, Montréal (Québec), H3C 1K3, Canada

---Ultrasonic guided waves are now routinely used in non-destructive evaluation. In plate-like structures, three fundamental modes can propagate, namely A0, S0 and SH0. Most of the guided wave literature has thus far focused on the use of A0 and/or S0 because these modes are easy to generate in plate-like structures using standard piezoceramic transducers. Yet, at low frequency, A0 and S0 are dispersive. The consequence of dispersion is that signal processing becomes complex for long propagation distances. SH0, on the other hand, has the particularity of being the only non-dispersive guided wave mode. Omnidirectional transduction of SH0 requires a rotational surface stress which cannot be easily generated using standard piezoceramic transducers. This project investigated the use of piezoceramic shear plates cut into six trapezoids bonded to a plate in order to form a discretized circle. The individual elements of the hexagon were then synchronized to generate shear surface stress simultaneously. The external diameter of the discretized circle was chosen to be half the SH0 wavelength at the desired center frequency. Finite element simulations using the Comsol Multiphysics environment showed that in a 1.6 mm aluminum plate the modal selectivity of the transducer was more than 30 dB at 100 kHz. The concept was then validated experimentally on a 1.6 mm aluminum plate. The 3D experimental displacement field was measured using a laser Doppler vibrometer system. The experimental modal selectivity was 25 dB.

9:50 AM

A PVDF Array Sensor for Lamb Wave Reception for Aircraft Structural Health Monitoring

---Baiyang Ren and Cliff Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA, 16802

---Fracture critical structures need structural health monitoring (SHM) to improve safety and reliability as well as reduce downtime and maintenance costs. Lamb waves provide promising techniques for on-line SHM systems because of their large volumetric coverage and good sensitivity to defects. Extensive research has focused on using features derived from time signals obtained at sparse locations distributed across the structure. Commonly used features are wave amplitude, energy, and time of arrival. However, these features are not sufficient to represent the modal content of received Lamb waves, which usually carry valuable information about the existence and characteristics of defects. Wave scattering at a defect often results in mode conversions in both transmitted and reflected waves. Features of amplitude reduction or change of time of arrival can all be interpreted as a result of mode conversion. This work is focused on the design of a 1D array sensor such that received wave signals at equally spaced locations are available for modal analysis in the wavenumber-frequency domain. PVDF (polyvinylidene fluoride) is selected as the active material of the sensor because of its low interference with wave fields in structures and good capability in suppressing cross talk among different channels. The PVDF array sensor is fabricated to have 16 independent channels and its capability to detect and characterize different types of defects is demonstrated experimentally.

10:30 AM

Wave Mode Extraction from Multimodal Guided Wave Signal in a Plate

---**Madis Ratassepp** and Zheng Fan, Nanyang Technological University, School of Mechanical and Aerospace Engineering, 50 Nanyang Avenue, Singapore 639798

---One of the challenges in wide-band multimode guided wave testing is the decomposition of multimodal response signal into individual components. In this study the post-processing procedure based on plate wave mode orthogonality is proposed to extract individual waveforms at a plate edge from multimodal signals [1]. To obtain the amplitudes of the individual modes, the numerically predicted modal through-thickness stress and displacement field values are used in the orthogonality relation. Two-dimensional wave propagation cases at normal incidence are considered: signals of overlapping fundamental Lamb modes A0 and S0 and shear horizontal modes SH0 and SH1 are analyzed. The performance of the mode extraction technique is evaluated by processing the signals obtained from finite element (FE) modeling and experimental measurements. The required experimental displacement components at the plate edge are measured by 3D Scanning Laser Doppler Vibrometer (3D SLDV) [2]. It is demonstrated that individual modes can be extracted with good accordance with the original waveforms from numerical predictions and experimental measurements.

References:

1. M. Ratassepp, A. Klauson, F. Chati, F. Leon, D. Decultot, G. Maze, and M. Fritzche, “Application of orthogonality-relation for the separation of Lamb modes at a plate edge: Numerical and experimental predictions,” Ultrasonics, 57, pp 90-95 (2015).
2. M. Johansmann, J. Sauer, “Reflectivity and thus a low noise level in the velocity signal”, Symp. Int. Automotive Technol. 26–052, pp 631–637 (2005).

10:50 AM

Defect Depth Sizing Using Guided Waves

---**Adam C. Cobb** and Jay L. Fisher, Sensor Systems and NDE Technology Department, Southwest Research Institute, San Antonio, TX 78228

---Guided wave inspection technology is most often applied as a survey tool for pipeline inspection, where relatively low frequency ultrasonic waves, compared to those used in conventional ultrasonic nondestructive evaluation (NDE) methods, propagate along a structure; discontinuities cause a reflection of the sound back to the sensor for defect detection. Although the technology can be used to accurately locate a defect over long distances, the defect sizing performance, especially for defect depth estimation, is much poorer than other local NDE approaches. Estimating defect depth, as opposed to other parameters, is of particular interest for failure analysis of many structures. At present, most guided wave technologies estimate the size of the defect based on the reflected signal amplitude from the defect compared to a known geometry reflection, such as a circumferential weld in a pipeline. This process, however, requires many assumptions to be made, such as weld geometry and defect shape. Furthermore, it is highly dependent on the amplitude of the defect reflection, which can vary based on many factors, such as attenuation and sensor installation. To improve sizing performance, especially depth estimation, and do so in a way that is not strictly amplitude dependent, SwRI has developed an approach to estimate the depth of a defect based on a multimodal analysis. This approach eliminates the need of using geometric reflections for calibration and can be used for both pipeline and plate inspection applications. To validate the approach, a test set was manufactured on plate specimens with flaws of different widths and depths ranging from 10% to 50% of total wall thickness. Over 20 defect data sets were collected from this defect set by using a guided wave sensor to collect data at various distances from the flaws. The defects were sized with an error standard deviation of 4.7% of the wall thickness. A description of the initial multimodal sizing strategy and results will be discussed.

11:10 AM

Monitoring Thicknesses Along a Line Using Guided Waves

---**R. Howard** and F. Cegla, NDE Group, Imperial College London, Exhibition Road, South Kensington SW7 2AZ, United Kingdom

---Guided wave technology has been successfully implemented in the field of NDT as a defect screening technique for many years now. The existing techniques are able to detect large defects in pipes albeit with limited sensitivity since the technique operates at low frequencies (10-70kHz). Ultrasonic wall thickness monitoring is also a well-established technique; using frequencies in the MHz range. These spot measurements are able to measure precise wall thicknesses but are very spatially selective. This project aims to explore the middle ground, using higher frequency guided waves to increase sensitivity whilst increasing the spatial area covered. Guided waves (SH0,SH1, and A0 modes) were sent between two transducers in a plate (simulating the propagation of a guided wave around the circumference of a pipe) and the time traces of the transmitting and receiving transducers were analysed for changes in the reflection coefficient, transmission coefficient and the group velocity as different defects were introduced into the plate. It is shown that the guided wave-defect interactions were too distorted for accurate thickness profiles to be extracted from average thickness measurements along a line. The method, however, is a fast tool for qualitative defect screening.

11:30 AM

Practical Ultrasonic Damage Detection on Pipelines Using Component Analysis Methods

---**Chang Liu**, Jacob Dobson, and Peter Cawley, Imperial College, 310A City & Guilds Building, Exhibition Road, London SW7 2AZ, United Kingdom

---Guided wave ultrasonic testing is an effective tool for detecting damage on pipe structures because guided waves can propagate over a long distance and cover the full cross-section of pipe, so giving 100% volume coverage. Historically, most guided wave testing has been done with deployable sensors on a one-off test (NDT) basis. However, permanently installed systems are now commonly used, giving the opportunity to convert to SHM rather than NDT. In conventional SHM, damage can be detected by subtracting a measurement from a baseline record, after properly compensating for any temperature difference between the tests. However, it is often seen in practical implementation that temperature compensation methods cannot perfectly remove the benign variations produced by complex environmental and operational conditions (EOCs), leaving residual noise that can mask the damage signal. With the recent advances in computing and storage systems, it has become feasible to process a batch of historical records, instead of only comparing the current measurement with one baseline, and data-driven approaches have been developed to detect small damage signals in the presence of EOC variations more robustly. In this paper, we evaluate two recently-developed, data-driven damage detection methods based on component analysis: singular value decomposition (SVD) and independent component analysis (ICA). We implement the two methods to process synthetic dataset that contains superposition of experimental ultrasonic records collected at varying environmental conditions, and artificially generated damage signals at various locations. Such a synthesis process provides us the flexibility to investigate the performance of subjected methods at different EOC conditions without damaging the pipe, which is prohibitively expensive if a large number of scenarios are to be investigated. We then validate the results from using experimental guided wave records taken from permanently installed transducer rings on an industrial scale pipe system that consists of bends, welds, and a flange. During the data collection, three flat-bottom holes were drilled gradually at different locations along the pipe to a maximum of 0.75% of the cross section area. We compare the performance of the SVD, ICA, and the conventional baseline-subtracted residual method in two aspects. First, we evaluate how well the extracted damage feature resembles the true damage in terms of location and amplitude. We accomplish this by comparing the damage feature with the true damage and computing the receiver operating characteristics, which plots the probability of detection against the probability of false alarm. Second, we evaluate how well the damage features extracted from sequential ultrasonic measurements track the true progression of the damage, by using statistical trend analysis. Our results suggest that both SVD and ICA can effectively identify the damage in the presence of EOC variations, with superior performance compared to the conventional residual method.

11:50 AM

Investigation on Empowering One Direction Emission of Guided Waves to Avoid Undesired Reflections from Other Pipe Attachments.

---**Peter W. Tse** and Fang Zhou, the Smart Engineering Asset Management Laboratory (SEAM) and the Croucher Optical Nondestructive Testing Laboratory (CNDT), Department of Systems Engineering & Engineering Management, City University of Hong Kong, Hong Kong, China

---An in-service pipe always contains elbows and joints at the ends of the pipe. Since the emitted guided waves from a transducer array is bi-directional, any attachments located at both ends of the pipe will cause reflections. For building pipes that are partially covered by wall, the transducer array must be installed near one end of the pipe. If there is elbow or joint connected to that end of the pipe, high reflections generated from the elbow or joint are inevitable. Such reflections may interfere the detection of reflections caused by true defect exists along the pipe body. Hence, to minimize such undesired interference, one must employs some smart device or algorithm so that it can reduce the emission of guided wave from one direction but enhance the emission from the other direction. To achieve such purpose, two identical transducer arrays must be installed on the same pipe but with a smartly and specially calculated distance apart from the mounting locations of these two arrays. The distance is to ensure there is a proper time delay for emitting the second array after the emission of the first array. Our designed processes are listed as follow. Firstly, two identical transducer arrays that could emit $L(0,1)$ guided waves were mounted on a pipe with a specific distance apart from their mounting locations. The distance was determined after calculating the necessary time delay. Secondly, the guided waves generated from the two arrays are combined together to create the desired superimposing effect. With the help of simulation and finite element analysis, such single direction guided wave was successfully generated and tested. By accurately adjusted the time delay, results showed that it is possible to minimize the emitted guided waves in one direction and then empower the guided waves in another direction. Hence, the reflections generated from elbows and joints at one end of the pipe has been minimized, whilst, the emission of guided wave in the other direction has been increased so that the sensitivity of detecting defects along the pipe can be enhanced.---The work described in this paper was fully supported by a grant from the Research Grants Council (Project No. CityU _122513) and a grant from the Innovation and Technology Commission (Project No. ITS/061/14FP) of the Government of Hong Kong Special Administrative Region, China.

Session 8

SESSION 8

ADDITIVE MANUFACTURING AND MATERIAL CHARACTERIZATION

Martin Spies and Evgueni Todorov, Co-Chairpersons
Nicollet D2

8:30 AM **Additive Manufacturing: NDE Challenges and Opportunities**
---**Martin Spies**, **John Slotwinski,** The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099; Martin Spies, Fraunhofer Institute for Nondestructive Testing IZFP, Campus E3 1, 66123 Saarbrücken, Germany

8:50 AM **Nondestructive Evaluation of Additive Manufactured Aerospace Components with Complex Shape. A Literature Review**
---**Evgueni Todorov**, Roger Spencer, Sean Gleeson[1], Scott Newhouse, Mahdi Jamshidinia, and Shawn Kelly, Edison Welding Institute (EWI), 1250 Arthur E. Adams Dr., Columbus, OH 43221; [1]Progenero Products, 609 14th Street SW, Suite 100, Loveland, CO 80537

9:10 AM **On- and Offline Ultrasonic Characterization of Components Build by SLM Additive Manufacturing**
---Hans Rieder and **Martin Spies**, Fraunhofer Institute for Nondestructive Testing IZFP, Campus E3 1, 66123 Saarbrücken, Germany; Joachim Bamberg and Benjamin Henkel,
MTU Aero Engines AG, Department TAFP, Dachauerstrasse 665, 80995 Munich, Germany

9:30 AM **Inspection of Additive Manufacturing Parts Using Laser Ultrasonics**
---**Daniel Lévesque**, Martin Lord, Christophe Bescond, and Jean-Pierre Monchalin, National Research Council Canada, Boucherville, Qc, Canada; Priti Wanjara and Xinjin Cao, National Research Council Canada, Montreal, Qc, Canada

9:50 AM **Measuring Internal Features and Defects in AM Components Using X-Ray Computed Tomography**
---**G. Jones**, A. Grow[1], S. Hyde[1], and T. A. Palmer, Applied Research Laboratory, Pennsylvania State University, [1]The Timken Company, North Canton, OH 44706

10:10 AM **Break**

10:30 AM **WITHDRAWN - Ultrasonic Characterization and Assessment of Bonding between Adjacent Structures in Polymeric Additive Manufacturing**
---**Vinay Dayal** and Richard Livings, Iowa State University, Center for Nondestructive Evaluation and Department of Aerospace Engineering, Ames IA 50011

10:50 AM **Non-Destructive Evaluation for Additive Manufacturing**
---**Jethro Coulson**[1], Rikesh Patel[1], Steve Sharples[1], Adam Clare[2], Wenqi Li[1], Richard Smith[1], Matthias Hirsch[2], Chris Tuck[2], and Matt Clark[1]; [1]Applied Optics Group; [2]Additive Manufacturing and 3D Printing Group – University of Nottingham

11:10 AM **Relationship Between Near-Surface Ultrasonic Shear-Wave Backscatter and Grain Size in Metals**
---**Brady J. Engle**[1,2], Frank J. Margetan[1], and Leonard J. Bond[1,2,3], [1]Center for Nondestructive Evaluation, 1915 Scholl Road, 111 ASC II, Iowa State Univeristy, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011

11:30 AM **Statistical Flaw Characterization Through Bayesian Shape Inversion from Scattered Wave Observations**
---**Jerry McMahan**[2] and Amanda Criner[1], [1]Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson AFB, OH 45433-7817; [2]Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

11:50 AM **Creep-Induced Nonlinear Ultrasonic Changes in High Cr Ferritic Heat Resisting Steel Welded Joint**
---**Toshihiro Ohtani**, Takumi Honma, and Yutaka Ishii, Shonan Institute of Technology, Department of Mechanical Engineering, Fujisawa, Kanagawa, 251-8511, Japan; Masaaki Tabuchi and Hiromichi Hongo, National Institute for Materials Science, Tsukuba, Ibaraki, 305-0047, Japan; Masahiko Hirao, Osaka University, Graduate school of Engineering Science, Toyonaka, Osaka, 560-8531, Japan

12:10 PM **Lunch**

8:30 AM

Additive Manufacturing: NDE Challenges and Opportunities

---John Slotwinski, The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099; Martin Spies, Fraunhofer Institute for Nondestructive Testing IZFP, Campus E3 1, 66123 Saarbrücken, Germany

---Additive manufacturing (AM) processes are capable of producing highly complex and customized parts, without the need for dedicated tooling, and can produce parts directly from the part design information. These types of processes are poised to revolutionize the manufacturing industry, yet there are several challenges that are currently preventing more widespread adoption of AM technologies. Traditional NDE methods could be utilized in AM for pre-process, in-process and post-process applications. This talk will give an overview of AM technology, discuss the potential benefits and challenges of using NDE in AM applications, and give an update on current industrial and standardization efforts of NDE for AM.

8:50 AM

Nondestructive Evaluation of Additive Manufactured Aerospace Components with Complex Shape. A Literature Review

---Evgueni Todorov, Roger Spencer, Sean Gleeson[1], Scott Newhouse, Mahdi Jamshidinia, and Shawn Kelly, Edison Welding Institute (EWI), 1250 Arthur E. Adams Dr., Columbus, OH 43221; [1]Progenero Products, 609 14th Street SW, Suite 100, Loveland, CO 80537

---Nondestructive Evaluation (NDE) techniques are needed to validate the additive manufacturing (AM) process performance. The lack of adequate NDE techniques for examination before, during and after AM component fabrication was identified as one of the main current challenges [1]. A literature review was conducted to identify promising NDE techniques that could be used for post-process evaluation of metallic AM parts and components [2]. Laser Powder Bed Fusion (L-PBF) or Direct Metal Laser Melting (DMLM) and Electron Beam Powder Bed Fusion (EB-PBF) or Electron Beam Melting (EBM) were identified as the two promising candidates for the production of metallic components applicable to aerospace industry. The geometrical complexity of the AM components was recognized as a major factor for the selection of NDE techniques. A qualitative grouping of the AM components was reported in the literature review with Group 1 being the least and Group 5 (e.g., lattice structure) being the most complex geometry. Mechanisms of discontinuity formation and geometry deviations were discussed and analyzed. Unfused powder and pronounced surface roughness (unique to AM processes) for internal volumetric discontinuities were identified as additional factors affecting NDE performance. Application of various NDE modalities for AM components was discussed and presented in summary tables. An X-ray computed tomography (CT) was selected as one of the primary techniques for inspection of components with complex shapes, especially Group 4 and Group 5. Conclusions and recommendations for near- and mid-term research and development were also provided**.****---**The work was funded by the Air Force Research Laboratory (AFRL) under America Makes program. The authors would like to acknowledge generous support of the AFRL and America Makes.

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2. AFRL-RX-WP-TR-2014-0162, AMERICA MAKES: NATIONAL ADDITIVE MANUFACTURING INNOVATION INSTITUTE (NAMII), Project 1: Nondestructive Evaluation (NDE) of Complex Metallic Additive Manufactured (AM) Structures, June 2014.

9:10 AM

On- and Offline Ultrasonic Characterization of Components Build by SLM Additive Manufacturing

---Hans Rieder and **Martin Spies**, Fraunhofer Institute for Nondestructive Testing IZFP, Campus E3 1, 66123 Saarbrücken, Germany; Joachim Bamberg and Benjamin HenkelMTU Aero Engines AG, Department TAFP, Dachauerstrasse 665, 80995 Munich, Germany

---Additive manufacturing processes allow for the production of components by localized melting of successive layers of powder. In comparison with conventional, subtractive manufacturing such techniques provide considerably more freedom in designing and have a tremendous economic potential in view of saving resources. Starting out from a CAD-representation of the part to be build additive manufacturing is particularly interesting for the production of geometrically complex aero engine components. Using Selective Laser Melting (SLM), such sophisticated components have already been manufactured at MTU from the heat-resistant nickel alloy Inconel 718. For quality assurance, various techniques – online and offline – are employed such as materials' science investigations (metallographic inquiries, tensile tests) as well as nondestructive inspections. Online measurements are performed using optical tomography and ultrasound. In this contribution, we report on investigations in view of the influence of the process parameter 'laser power' on the microstructure of the manufactured component. It turned out that the online recorded A-scans allow inferring conclusions about the quality of the SLM process. To validate the ultrasonic results, metallographic and X-ray investigations have been performed. Offline measurements additionally show the potential to characterize anisotropies and variations in Young's modulus. On the basis of the obtained results, we currently develop the concept of a 'smart', additively manufactured test block for online process control and offline materials characterization using ultrasound.

9:30 AM

Inspection of Additive Manufacturing Parts Using Laser Ultrasonics

---Daniel Lévesque, Martin Lord, Christophe Bescond, and Jean-Pierre Monchalin, National Research Council Canada, Boucherville, Qc, Canada; Priti Wanjara and Xinjin Cao, National Research Council Canada, Montreal, Qc, Canada

---Additive manufacturing is a novel technology that is expanding very rapidly. For metallic parts, the powder bed approach, in which the laser or electron beam is scanned along a path predetermined according to the part design, is presently the most widely used. In contrast, the direct laser or electron beam deposition, which uses powder and/or wire feed, is particularly flexible for manufacturing or refurbishing of value-added components. Besides the dimensional accuracy, metallic structural parts such as those used in aero engines must be free of major defects such as cracks, lack of bonding between layers, and porosity. In addition, the microstructure characteristics should enable the desired mechanical performance. For these purposes, laser ultrasonics is very attractive due to its non-contact nature and is especially suited for the analysis of parts with complex geometries. In addition, the technique is well adapted to online implementation and real-time measurement during the manufacturing process. The inspection can be performed from either the top deposited layer or the underside of the substrate. In this work, a variety of results obtained off-line on INCONEL® 718 and Ti-6Al-4V coupons that were manufactured using laser powder or electron beam wire deposition are reported and discussed.

9:50 AM

Measuring Internal Features and Defects in AM Components Using X-Ray Computed Tomography

---**G. Jones**, A. Grow[1], S. Hyde[1], and T.A. Palmer, Applied Research Laboratory, Pennsylvania State University, [1]The Timken Company, North Canton, OH 44706

---Additive manufacturing (AM) techniques, particularly powder bed fusion processes, have the demonstrated capability of producing internal features which are difficult if not impossible to produce using traditional manufacturing methods. Due to limitations of accessibility and resolution, few NDE methods are capable of inspecting these geometries, particularly with the microstructures produced under the rapid solidification conditions created by the layer-by-layer fabrication process. Microfocus x-ray computed tomography (CT) has the ability to resolve internal features across a range of materials and microstructures, making it a candidate for the inspection of AM components. However, the resolution of the CT technique is not defined, making the calibration of the systems impossible. In this study, the microfocus CT method is used to evaluate embedded features in parts fabricated by the powder bed fusion AM process. The ability of the technique to detect and measure these features is quantified and compared to ultrasonic techniques and metallographic evaluation. These results show the promise of this technique for not only detecting defects but providing a measurement tool for visualizing and confirming the geometries and sizes of internal features.

10:30 AM

Ultrasonic Characterization and Assessment of Bonding between Adjacent Structures in Polymeric Additive Manufacturing

---Vinay Dayal and Richard Livings, Iowa State University, Center for Nondestructive Evaluation and Department of Aerospace Engineering, Ames IA 50011

---Non-homogeneous, layered structures (Figure 1 & 2) were observed in the production of parts by polymeric additive manufacturing. Previous work demonstrated that these materials do not fit the isotropic material model and suggested that they may be better fitted to a monoclinic model since complimentary shear velocity measurements gave differing results [1]. This work measures the full set of monoclinic elastic constants using ultrasonic velocities and mechanical testing as well as the directional properties of the ultrasonic dispersion and attenuation. Determining the elastic constants from mechanical testing and ultrasonic measurements gives significantly different results for this material which indicates dispersion caused by the visco-elastic nature of the material, the periodic microstructure, and the bond quality between adjacent voxels. The visco-elastic properties of the material was examined by DMA testing, while the bond quality was determined with double cantilever beam samples

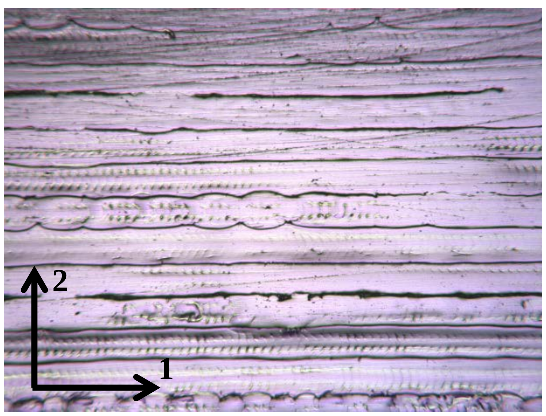

Figure 1. Micrograph of the printing plane showing a striated structure.

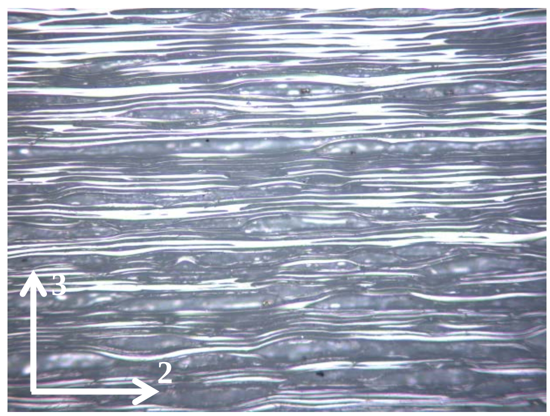

Figure 2. Micrograph of the plane perpendicular to the printing plane showing a striated structure.

Reference:

1. R. Livings, V. Dayal, D. Barnard, “Characterization of 3D Rapid Prototyped Polymeric Material by Ultrasonic Methods,” in *41st Review of Progress in Quantitative Nondestructive Evaluation*, 2015.

10:50 AM

Non-Destructive Evaluation for Additive Manufacturing

---**Jethro Coulson**[1], Rikesh Patel[1], Steve Sharples[1], Adam Clare[2], Wenqi Li[1], Richard Smith[1], Matthias Hirsch[2], Chris Tuck[2], and Matt Clark[1]; [1]Applied Optics Group; [2]Additive Manufacturing and 3D Printing Group – University of Nottingham

---Additive manufacturing (AM) is an important fabrication process in fields that include aerospace, automotive and medicine. Rapid prototypes of complex structures can be constructed using 3D metal printing; these structures will have high tensile strength that may not be constructed otherwise. However, variations in the AM build process can affect the quality of the metal structure. Defects such as print warps, cracks, gaps and holes built into the structure (e.g. due to unconsolidated metal powder) can be difficult to detect visually. Changes to the build speed, the process order or the print technology could affect sections of the printed component; this unknown micro-structure can lead to unknown material performance. Laser ultrasonic inspection is an attractive technique for AM inspection as it is can cope with the complex form factors of AM parts. SRAS (spatially resolved acoustic spectroscopy) is a method of characterizing material though laser generated surface acoustic waves. The grain structures of AM metal parts can be imaged using this system, which would include information on the size and orientation of the grain; this can be used to ascertain the material strength. In addition, this technique can be used to detect the print porosity (e.g. gaps or errors). Difficulties arise in performing laser ultrasound detection on optically rough samples; this paper presents work to date on capturing SRAS images of AM constructs. Images are taken of samples made using different 3D metal printing technologies including selective laser melting (SLM) and wire and arc additive manufacturing (WAAM). Whilst this is currently conducted offline, potentially, the presented inspection system could be performed in an online capacity as the components are printed, to verify mechanical properties and provide information to feed back into the build process.---This project is funded by EPSRC through RCNDE.

11:10 AM

Relationship Between Near-Surface Ultrasonic Shear-Wave Backscatter and Grain Size in Metals

---**Brady J. Engle**[1,2], Frank J. Margetan[1], and Leonard J. Bond[1,2,3], [1]Center for Nondestructive Evaluation, 1915 Scholl Road, 111 ASC II, Iowa State University, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011

---Backscattered ultrasonic microstructural noise can be used to estimate grain size in metals. However for normal-incidence immersion measurements the ring-down of the front-wall echo creates a "dead zone" where backscattered grain noise cannot be quantified. This poses a problem for near-surface grain sizing efforts. In this paper we explore the use of mode-converted 45-degree shear waves for near-surface grain sizing using a water immersion setup. We discuss how to accurately relate grain noise arrival time with depth of sound penetration in the metal. Then for a set of Ni-alloy specimens having near-equiaxed microstructures we correlate various backscattered noise attributes with grain sizes determined from micrographs. These noise attributes include both time-domain and frequency-domain characteristics. This work is supported by the Pratt & Whitney Center of Excellence at Iowa State University.

11:30 AM

Statistical Flaw Characterization Through Bayesian Shape Inversion from Scattered Wave Observations

---**Jerry McMahan**[2] and Amanda Criner[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, Wright Patterson AFB OH 45433-7817; [2]Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

---A method is discussed to characterize the shape of a flaw from noisy far-field measurements of a scattered wave. The scattering model employed is a two-dimensional Helmholtz equation which quantifies scattering due to interrogating signals from various physical phenomena such as acoustics or electromagnetics. The well-known inherent ill-posedness of the inverse scattering problem is addressed via Bayesian regularization. The method is based on the approach described in [1] which used the framework of [2] to prove the well-posedness of the infinite-dimensional problem and derive estimates of the error for a particular discretization approach. The method computes the posterior probability density for the flaw shape from the scattered field observations, taking into account prior assumptions which are used to describe any a priori knowledge of the flaw. We describe the computational approach to the forward problem as well as the Markov chain Monte Carlo (MCMC) based approach to approximating the posterior. We present simulation results for some hypothetical flaw shapes with varying levels of observation error and arrangement of observation points. The results show how the posterior probability density can be used to visualize the shape of the flaw taking into account the quantitative confidence in the quality of the estimation and how various arrangements of the measurements and interrogating signals affect the estimation. – This work is funded by the Air Force Office of Scientific Research.

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1. T. Bui-Thanh and O. Ghattas, “An analysis of infinite-dimensional Bayesian inverse shape acoustic scattering and its numerical approximation,” *SIAM/ASA J. Uncertainty Quantification*, Vol. 2, pp. 203-222 (2014).
2. A. M. Stuart, “Inverse problems: a Bayesian perspective”, *Acta Numerica*, 19, pp. 451-559 (2010).

11:50 AM

Creep-Induced Nonlinear Ultrasonic Changes in High Cr Ferritic Heat Resisting Steel Welded Joint

---Toshihiro Ohtani, Takumi Honma, and Yutaka Ishii, Shonan Institute of Technology, Department of Mechanical Engineering, Fujisawa, Kanagawa, 251-8511, Japan; Masaaki Tabuchi and Hiromichi Hongo, National Institute for Materials Science, Tsukuba, Ibaraki, 305-0047, Japan; Masahiko Hirao, Osaka University, Graduate school of Engineering Science, Toyonaka, Osaka, 560-8531, Japan

---High Cr ferritic heat resisting steel, ASME Grade 122 (11Cr-0.4Mo-2W-CuVNb) has been used for boiler components in ultra-supercritical (USC) thermal power plants at approximately 873 K. The creep life of the welded joints in this steel decreased as a result of Type IV creep damage that forms in the heat-affected zone (HAZ) under long-term use at high temperatures [1]. In this study, we investigated the relationship between microstructural change and the evolutions of two nonlinear acoustic characterizations with electromagnetic acoustic resonance (EMAR) [2] throughout the creep life in the welded joints and the correlation between two nonlinear acoustic characterizations. One was resonant frequency shift [3] and other three-wave mixing [4]. EMAR was a combination of the resonant acoustic technique with a non-contact electromagnetic acoustic transducer (EMAT) [2]. We used bulk wave EMAT, which transmits and receives shear wave propagating in thickness direction of a plate specimen. Creep tests of thick welded joints specimens were interrupted at several time steps at 873 K, and 90 MPa. Two nonlinear acoustic parameters and ultrasonic attenuation decreased from the start to 50% of creep life. After slightly increased, they rapidly increased from 80% of creep life to rupture. We interpreted these phenomena in terms of dislocation recovery, recrystallization, and restructuring related to the initiation and growth of creep void, with support from the SEM and TEM observation. This noncontact resonance-EMAT measurement can monitor the evolution of nonlinear acoustics throughout the creep life and has a potential to assess the Type IV creep damage advance and to predict the creep life of high Cr ferritic heat resisting steels.---This work was supported by JSPS KAKENHI Grant Numbers 25282106.

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2. M. Hirao and H. Ogi, “EMATs for science and industry: nondestructive ultrasonic measurements”, pp.1-92 and pp.135-196 (2003) Kluwer Academic Publishers, Boston.
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Session 9

SESSION 9

UT FUNDAMENTALS AND COMPOSITES

Joseph Turner and Robert Grandin, Chairpersons
Nicollet D3

8:30 AM **Effect of Surface Irregularity of Defects: Experiment and Computational Modeling**
---Jeong K. Na[2], Shaun Freed[2] and **James L. Blackshire**[1], [1]Air Force Research Lab (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Wyle Laboratories Inc., Advanced Technologies, Dayton, OH 45440

8:50 AM **High Performance Ultrasonic Field Simulation on Complex Geometries**
---Hamza Chouh[1], Gilles Rougeron[1], **Sylvain Chatillon[1] (presented by Vincent Dorval)**, Jean-Claude Lehl[2], Jean-Philippe Farrugi[2], and Victor Ostromoukhov[2], [1]CEA LIST, CEA Saclay – Digiteo Labs, PC 120, 91 191 Gif-Sur-Yvette Cedex, France; [2]LIRIS, UMR 5205, Univ. Lyon I, Team R3AM, Bât. Nautibus, 43 bd du 11 Novembre 1918, 69 622 Villeurbane, Cedex, France

9:10 AM **High Order Nystrom Method for Elastodynamic Scattering**
---Kun Chen, Praveen Gurrala, **Jiming Song**, and Ronald Roberts, Iowa State University, 2130 Coover Hall, Ames, IA 50011

9:30 AM **Simulating UT Measurements from Bolthole Cracks**
---**Robert Grandin,** Tim Gray, and Ron Roberts, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Stochastic Elastic Wave Scattering From 2D and 3D Random Rough Surfaces Using the Analytical Kirchhoff Theory**
---**Fan Shi**[1], Michael J. S. Lowe[1], Elizabeth Skelton[2], and Richard Craster[2], [1]Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom; [2]Department of Mathematics, Imperial College, London SW7 2AZ, United Kingdom

10:10 AM ***Break***

10:30 AM **Local Defect Resonance Used in Non-Destructive Testing**
---Wolfgang Adebahr, Igor Solodov, Markus Rahammer, Nikolai Gulnizkij, and **Marc Kreutzbruck**, University of Stuttgart, Institute of Plastics Engineering (IKT), Pfaffenwaldring 32, 70569 Stuttgart, Germany

10:50 AM **Ultrasonic Tracking of Ply Drops in Composite Laminates**
---**Robert A. Smith**, Luke J. Nelson, Martin J. Mienczakowski, and Paul D. Wilcox, Ultrasonics and NDT Group, University of Bristol, BS8 1TR, United Kingdom

11:10 AM **Quantification of Fatigue State in CFRP Using Ultrasonic Birefringence**
---Peter Fey and Marc Kreutzbruck**, Institut fur Kunststofftechnik, University of Stuttgart, Fpaffenwaldring 32, 70569, Stuttgart, Germany**

11:30 AM **In-situ Damage Monitoring and Analysis of Matrix Cracking in Continuous Fiber Reinforced Ceramic Composites**
---**Travis Whitlow**[1], Eric Jones[2], and Craig Przybyla[2], [1]University of Dayton Research Institute, Dayton, OH 45469; [2]Air Force Research Laboratory, WPAFB, OH 45469

11:50 AM **WITHDRAWN - A Generic Hybrid Modelling Tool for Guided Ultrasonic Wave Inspection -**
---**Manoj Reghu**[1,2] and Prabhu Rajagopal[1], [1]Center for Nondestructive Evaluation and Department of Mechanical Engineering, IIT Madras; [2]Defence Research & Development Laboratory (DRDL), Hyderabad, India

12:10 PM ***Lunch***

8:30 AM

Effect of Surface Irregularity of Defects: Experiment and Computational Modeling

---Jeong K. Na[2], Shaun Freed[2] and James L. Blackshire[1], [1]Air Force Research Lab (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Wyle Laboratories Inc., Advanced Technologies, Dayton, OH 45440

---Internal defects, especially cracks, oriented vertically to the accessible surface of a structure or component are commonly inspected with mode converted shear waves using a contact angle block or in an immersion tank. Depending on the interfacial surface morphology of the crack and the polarization direction of shear mode ultrasonic waves, reflected ultrasonic signals from the crack interface can be complex and hence resulting less accurate inspection results in terms of determining size and shape. In this work, the effect of surface irregularity of defects has been investigated experimentally with an immersion inspection set up generating 10 MHz 35-degree mode converted shear waves to detect various shapes of EDM notches and a surface breaking fatigue crack in metallic test specimens. In addition, efforts have been made to develop a computational model to understand how ultrasonic waves interact with surface irregularities of defects. The results of both experiment and computational model are presented and discussed in detail.

8:50 AM

High Performance Ultrasonic Field Simulation on Complex Geometries

---Hamza Chouh[1], Gilles Rougeron[1], **Sylvain Chatillon**[1], Jean-Claude Iehl[2], Jean- Philippe Farrugi[2], and Victor Ostromoukhov[2], [1]CEA LIST, CEA Saclay – Digiteo Labs, PC 120, 91 191 Gif-Sur-Yvette Cedex, France; [2]LIRIS, UMR 5205, Univ. Lyon I, Team R3AM, Bât. Nautibus, 43 bd du 11 Novembre 1918, 69 622 Villeurbane, Cedex, France

---Ultrasonic field simulation is a key ingredient for the design of new testing methods as well as a crucial step for NDT inspection simulation. As presented in a previous paper [1], CEA-LIST has worked on the acceleration of these simulations focusing on simple geometries (planar interfaces, isotropic materials). In this context, significant accelerations were achieved on multicore and GPU (Graphics Processing Unit), bringing the execution time of realistic computations in the 0.1 s range. In this paper, we present recent works that aim at similar performances on a wider range of configurations. We adapted the physical model used by the CIVA platform to design and implement a new algorithm providing a fast ultrasonic field simulation that yields nearly interactive results for complex cases. The improvements over CIVA pencil-tracing method include adaptive strategies for pencil subdivisions to achieve a good refinement of the sensor geometry while keeping a reasonable number of ray-tracing operations. Also, interpolation of the times of flight was used to avoid time consuming computations in the impulse response reconstruction stage. To achieve the best performance, our algorithm runs on multi-core superscalar CPUs and uses high performance specialized libraries such as Intel Embree for ray-tracing, Intel MKL for signal processing and Intel TBB for parallelization. We validated the simulation results by comparing them to the ones produced by CIVA on identical test configurations including mono-element and multi-elements transducers, homogeneous, meshed 3D CAD specimens, isotropic and anisotropic materials and wave paths that can involve several interactions with interfaces. We show performance results on complete simulations that achieve performance in the 1s range.

Reference:

1. A Fast Ultrasonic Simulation Tool Based on Massively Parallel implementation, J. Lambert et al. , QNDE 2013, 22-25 July, 2013, Baltimore, USA.

9:10 AM

High Order Nystrom Method for Elastodynamic Scattering

---Kun Chen, Praveen Gurrala, **Jiming Song**, and Ronald Roberts, Iowa State University, 2130 Coover Hall, Ames, IA 50011

---Elastic waves in solids find important applications in ultrasonic non-destructive evaluation. The scattering of elastic waves has been treated using many approaches like the finite and boundary element method and Kirchhoff approximation. In this work, we propose a novel accurate and efficient high order Nystrom method to solve the boundary integral equations for elastodynamic scattering problems. This approach employs high order geometry description for the element, and high order interpolation for fields inside each element. Compared with the boundary element method, this approach makes the choice of the nodes for interpolation based on the Gaussian quadrature, which renders matrix elements for far field interaction free from integration, and also greatly simplifies the process for singularity and near singularity treatment. The proposed approach includes a novel efficient singularity and near singularity treatment that makes the solver able to handle extreme geometries like very thin penny-shaped crack. Numerical results will be presented to validate the approach. By using the frequency domain response and performing the inverse Fourier transform, we also report the time domain response of flaw scattering.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

9:30 AM

Simulating UT Measurements from Bolthole Cracks

---Robert Grandin, Tim Gray, and Ron Roberts, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Analytical computer models of UT measurements are becoming more prominent in evaluating NDE methods – a process known as Model Assisted Probability of Detection, or MAPOD. As inspection requirements become more stringent, the respective models become more complex. An important application for aerospace structures involves inspection for cracks near boltholes in plate and layered structures. This presentation describes a project to develop and validate analytical models for bolthole crack inspection, as well as to implement and demonstrate those models within an integrated graphical interface which can be used to simulate these inspections. The work involves a combination of approximate, paraxial, bulk-wave models as well as more rigorous, analytical models that include both bulk and surface/plate modes. The simpler models have greater flexibility and efficiency for handling complex geometry, while the more exact models are useful for benchmarking and assessing the accuracy of the paraxial versions. Model results will be presented for bolthole cracks in both single and multi-layered components and will be compared to available measured results. Extensions of the models to more complex geometries and materials and other future development plans will also be discussed.**---**This work is funded by AFRL/RXCA and by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation and was performed at Iowa State University.

9:50 AM

Stochastic Elastic Wave Scattering From 2D and 3D Random Rough Surfaces Using the Analytical Kirchhoff Theory

---**Fan Shi**[1], Michael J. S. Lowe[1], Elizabeth Skelton[2], and Richard Craster[2], [1]Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom; [2]Department of Mathematics, Imperial College, London SW7 2AZ, United Kingdom

---Analytical elastodynamic Kirchhoff formulae are derived using the stationary phase approach to analyze the stochastic scattering from 2D and 3D rough surfaces. The theoretical solutions are compared with results from Monte Carlo simulations. Good agreements are found for all incidence/scattering angles over a range of values of the roughness within the limits of the validity of the Kirchhoff approximation (KA). Thus the expected scattering of elastic waves, including mode conversions and depolarization, from statistical descriptions of rough surfaces, can be predicted rapidly for any choice of the parameters within the range of validity of the KA. In addition, the theoretical formulae are applied to illustrate and quantitatively explain the difference of the scattering behaviour between 2D and 3D, for example that the 3D rough surfaces produce significantly less diffuse field than 2D due to the spatial averaging effect. This effect can be expressed explicitly as a function of the surface dimension, correlation length and the rms value. Furthermore, it is shown using the analytical formulae that for certain roughness larger scattering intensity is observed in the backscattering direction than in the specular direction.

10:30 AM

Local Defect Resonance Used in Non-Destructive Testing

---Wolfgang Adebahr, Igor Solodov, Markus Rahammer, Nikolai Gulnizkij, and **Marc Kreutzbruck**, University of Stuttgart, Institute of Plastics Engineering (IKT), Pfaffenwaldring 32, 70569 Stuttgart, Germany

---Fiber reinforced plastics (FRP) are being used in a large number of application with long expected lifetimes, such as wind energy or aerospace industry. To ensure a safe operation, it is indispensable to reveal serious defects which decrease the mechanical properties extremely. Ultrasonic wave-defect interaction is a background of ultrasound activated techniques for imaging and non-destructive testing (NDT) of materials and industrial components. The interaction, first, results in acoustic response of a defect, which provides attenuation and scattering of ultrasound used as an indicator of defects in conventional ultrasonic NDT. The derivative ultrasonic-induced effects include e.g. nonlinear, thermal, acousto-optic, etc. responses also applied for NDT and defect imaging. These secondary effects are normally relatively inefficient so that the corresponding NDT techniques require an elevated acoustic power and stand out from conventional ultrasonic NDT counterparts for their specific instrumentation particularly adapted to high-power ultrasonics. In this paper, a consistent way to enhance ultrasonic, optical and thermal defect responses is suggested by using selective ultrasonic activation of defects based on the concept of local defect resonance (LDR). A strong increase in vibration amplitude at LDR enables to reliably detect and visualize the defect as soon as the driving ultrasonic frequency is matched to the LDR frequency. This also provides a high frequency selectivity of the LDR-based imaging,

i.e. an opportunity of detecting a certain defect among a multitude of other defects in material. Some examples are shown how to use LDR in non-destructive testing techniques like Vibrometry, Thermography and Shearography in order to enhance the defect visualization. Both, simulation and experiments are discussed in a variety of composite materials and components.

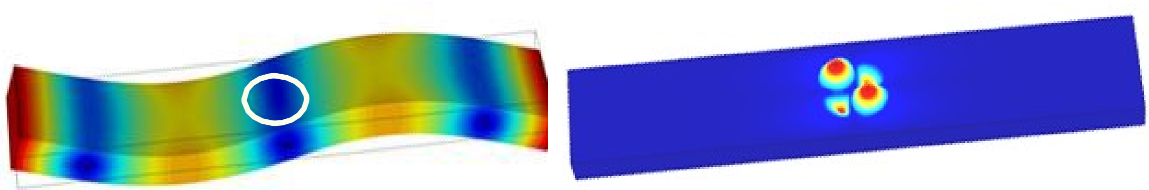

Figure 1. LDR frequency simulation of a flat-bottomed hole (indicated by solid white line) in PMMA left: false color representation of out-of-plane component at 1.5 kHz (no LDR); right: excitation at 23.3 kHz generates LDR effect.

References:

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10:50 AM

Ultrasonic Tracking of Ply Drops in Composite Laminates
---**Robert A. Smith**, Luke J. Nelson, Martin J. Mienczakowski, and Paul D. Wilcox,
Ultrasonics and NDT Group, University of Bristol, BS8 1TR, United Kingdom

---As the shapes of composite components become more adventurous, tracking internal locations of ply drops and detecting any tape gaps or overlaps will be crucial to assure conformance to design. The true potential of ultrasound has yet to be exploited for this objective due to the apparent complexity of the ultrasonic response and the assumption that interference between signals from plies is random, confusing and of little use. As a result, most ultrasonic inspection of composites targets undesirable defects that either attenuate or reflect ultrasound, regarding ply reflections as undesirable ‘noise’. The work presented here extends the ply-orientation mapping of the last two decades by introducing a systematic approach to optimizing the ultrasonic response from the plies, minimizing interference between plies and demonstrating that accurate maps of plies can be produced. The key to this method is the ultrasonic analytic signal and understanding how it interacts with plies and the resin-rich layers between them. In certain circumstances of frequency and bandwidth, the instantaneous phase locks onto the resin-rich layers and the instantaneous amplitude indicates the validity of this condition – see Figure 1.

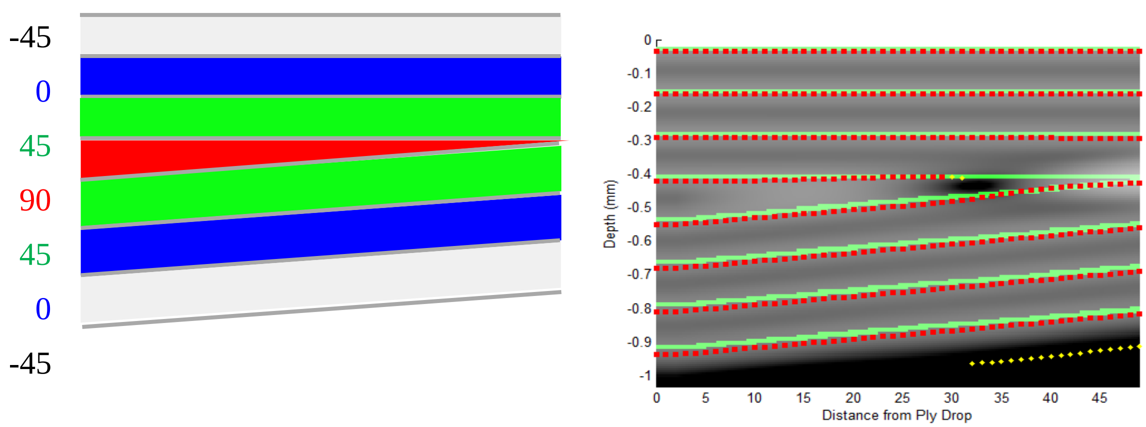


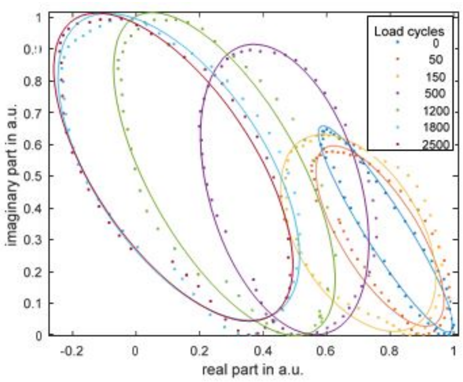
Figure 1. One type of ply drop, shown schematically (left), where fibers fill the wedge formed as the adjacent plies come together. Ultrasonic tracking is shown using analytical modelling of ultrasonic response (right), where the grayscale background is instantaneous amplitude, green lines are resin-rich layer locations in the model and red dots are locations of a specific instantaneous phase; yellow dots are points of correct phase but low amplitude.
Analytical modelling is used to explain the interaction between ultrasound and composite plies in various ply-drop scenarios, with reference to experimental results. Optimization of ultrasonic data acquisition will also be discussed and demonstrated experimentally. This research is part of a Fellowship in Manufacturing funded by the UK Engineering and Physical Sciences Research Council (EPSRC) aimed at underpinning the design of more efficient composite structures and reducing the environmental impact of travel.

11:10 AM

Quantification of Fatigue State in CFRP Using Ultrasonic Birefringence

---Peter Fey and **Marc Kreutzbruck**, Institut fur Kunststofftechnik, University of Stuttgart, Pfaffenwaldring 32, 70569, Stuttgart, Germany

---Fiber reinforced Plastics are widely used in high performance application areas such as aerospace, automotive and wind energy. They are preferred over classic materials such as metals because of their superior weight to stiffness ratio. When subjected to cyclic or static loading, micro-cracks develop and hence their stiffness degrades [1], [2]. The rate of stiffness degradation depends on the angle between the fibers and the applied load. Because commonly used fiber reinforced composites consist of multiple layers with different fiber directions to cope with different loads applied to the material, the stiffness degradation has to be analyzed for each fiber direction. One method to analyze the stiffness degradation in fiber reinforced materials is ultrasonic birefringence. A birefringent effect as it is known for light in optics is also observed for ultrasonic shear waves in fiber reinforced composites because of their elastic anisotropy. The role of the polarization dependent refractive index is taken by the propagation velocity of shear waves. If polarized parallel to the fiber direction they have a higher velocity than polarized perpendicularly to the fiber direction.



The velocity depends on shear stiffness of the material. A model to predict the behavior of shear waves in multi-ply layups has been presented previously [3]. That model was used to manually match measured and simulated phase and amplitude curves for waves that traversed the material under different angles between polarization direction of the emitting transducer and fiber direction in the first ply. Here another mode of interpreting the simulated results isused: amplitude and phase for each transducer orientation angle are combined to a complex number. Displaying them in the complex plane for one half rotation of the transducer yields an ellipse, as is shown by the graph below which shows results from different fatigue states of a CFRP specimen (dots: measured, lines: fitted). Semi axis lengths and orientation can be obtained by Fourier transform and are used to numerically fit the simulation to measured data. For synthetic data of a quasi-isotropic layup, the shear stiffness of each fiber direction was determined with an average precision of 20% by the fitting algorithm.

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11:30 AM

In-situ Damage Monitoring and Analysis of Matrix Cracking in Continuous Fiber Reinforced Ceramic Composites

---**Travis Whitlow**[1], Eric Jones[2], and Craig Przybyla[2], [1]University of Dayton Research Institute, Dayton, OH 45469, [2]Air Force Research Laboratory, WPAFB, OH

---Continuous ceramic fiber reinforced ceramic matrix composites or CMCs offer an innovative defect tolerant structural material for temperature regimes inaccessible to high temperature metals. When subject to application environments, these materials exhibit damage and degrade over time depending on the severity of those conditions. The ultimate strength of CMCs is dictated by the properties of the load bearing fibers, but matrix cracking weakens the composite and can expose the load bearing fibers to harsh environments. The objective of the work performed here was to develop a methodology for in-situ detection and monitoring of transverse matrix cracking in continuous fiber reinforced CMCs. First, the initiation and growth of matrix cracking are measured and triangulated via acoustic emission (AE) detection. High amplitude events can be associated with initiation of large matrix cracks and when there is a localization of high amplitude events, a measurable effect on the strain field can be observed. Full field surface strain measurements were obtained using digital image correlation (DIC). An estimation of the matrix crack density as well as its distribution was performed in real time. Various techniques were employed post-test including automated robotic sectioning and florescent dye penetrant inspection to determine matrix crack density. The AE results are compared and contrasted to the more labor intensive inspection techniques.

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11:50 AM

A Generic Hybrid Modelling Tool for Guided Ultrasonic Wave Inspection

---**Manoj Reghu**[1,2] and Prabhu Rajagopal[1], [1]Center for Nondestructive Evaluation & Dept. of Mechanical Engineering, IIT Madras; [2]Defence Research & Development Laboratory (DRDL), Hyderabad, India

---An understanding of modal characteristics in structures is essential for the application of existing and new guided ultrasonic wave Non Destructive Evaluation (NDE) technologies and methods. Analysis of guided wave phenomena is challenging because of their complex dispersive and multimodal nature and fully numerical solution procedures often impose a large computational cost. Although hybrid models combining numerical models for wave scattering with rapid calculations for wave propagation have long been considered to address this problem, typically such models require modification of the base code of the solution procedure. This paper discusses the development of a generic hybrid model that combines the advantages of analytical calculations and numerical models. This is achieved within the framework of the 'pill-box' approach that connects incoming and outgoing fields in the wave propagation and scattering models using generic bridge-codes. The concept and implementation of the hybrid model as applied to low-frequency guided wave propagation and scattering from canonical defects in flat plates are presented. The implementation relies on decomposition of multi-modal fields into constituent modes and is hence currently limited to the far-field in the scattering models.

Session 10

SESSION 10
6th EAW
Lakeshore A

ADVANCED METHODS
Michele Carboni and John Aldrin, Co-Chairpersons

8:30 AM **New Challenges for the Quantification of the NDT Reliability**
---**Mato Pavlovic**[1], Christina Müller[1], and Ulf Ronneteg[2], [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany; [2]SKB Swedish Nuclear Fuel and Waste Management Co., Oskarshamn, Sweden

9:10 AM **PAUT Inspection of Copper Canister: Structural Attenuation and POD Formulation**
---**A. Gianneo**[1], M. Carboni[1], C. Mueller[2], and U. Ronneteg[3], [1]Dipartimento di Meccanica, Politecnico di Milano, Via La Masa 1, 20156 Milano; [2]BAM, Berlin, Germany; [3]SKB, Oskarshamn Sweden

9:30 AM **Model-based POD Study of Manual Ultrasound Inspection and Sensitivity Analysis Using Metamodel**
---**Guillemette Ribay**, Xavier Artusi, and Frédéric Jenson, CEA LIST Bat 565 PC120, 91191 Gif sur Yvette, France; Christopher Reece, EDF - DIN-CEIDRE, Etudes-ETC, 2 rue Ampère, 93206 Saint Denis, France; Pierre-Emile Lhuillier, Departement MMC, EDF R&D, Sites des Renardieres, 77818 Moret-sur-Loing, France

9:50 AM **POD Evaluation Using Simulation: Progress, Practice and Perspectives**
---**Nicolas Dominguez**, Airbus Group Innovations, Toulouse, France; Frederic Reverdy, CEA-LIST, Toulouse, France

10:10 AM ***Break***

ADVANCED METHODS
Pierre Calmon and Norio Nakagawa, Co-Chairpersons

10:30 AM **Advanced Reliability Methods – A Review**
---**David Forsyth**, TRI/Austin, 9225 Bee Caves road, Austin, TX 78733

11:10 AM **How Much Information Do We Need? A Reflection on the Correct Use of Real Defects in POD Evaluations**
---**Daniel Kanzler**[1] and Christina Müller[1], [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany

11:30 AM **Improving the Reliability of POD Curves in NDI Methods Using a Bayesian Inversion Approach for Uncertainty Quantification**
---Anis Ben Abdessalem, Frédéric Jenson, **Pierre Calmon**, CEA LIST, 91191 Gif-sur-Yvette, France

11:50 AM **2D Detectability Criteria and Its Implication for Developing a Standard Observer Model for the Human Component of Inspection Modeling**
---**Joe Gray**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

8:30 AM

New challenges for the quantification of the NDT reliability

Mato Pavlovic [1], Christina Müller[1], Ulf Ronneteg [2], [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany, [2]SKB Swedish Nuclear Fuel and Waste Management Co., Oskarshamn, Sweden

As the non-destructive testing (NDT) methods develop and become available for most diverse applications, they enter various segments of the industrial sectors. But new applications also present new challenges to the NDT systems to reliably and consistently detect flaws. The reliability of the NDT systems needs to be evaluated and quantified in applications where missed flaws can lead to catastrophic consequences. The conventional approach of quantification, by means of the probability of detection (POD) curve as a function of the single most important influencing parameter, is not more valid for complex inspection cases, where several factors at the same time have a large influence on the POD. This difficulty called for new reliability models to be developed. The multi-parameter model allows evaluation and quantification of the reliability as a function of several influencing parameters. It relies on the mathematical simulation of the NDT process to reduce time and cost of the evaluation but also on the experiment, to properly address the influence of all factors that influence the POD. Examples of the application of the model in nuclear industry will be shown. The reliability of NDT methods is a part of the total risk assessment of the final repository for spent nuclear fuel in Sweden and Finland. The quantification of reliability of NDT systems used to inspect copper and cast iron components of the canister for storage of the spent nuclear fuel, considering several influencing factors on the POD, will be presented.

9:10 AM

PAUT Inspection of Copper Canister: Structural Attenuation and POD Formulation

---A. Gianneo[1], M. Carboni[1], C. Mueller[2], and U. Ronneteg[3]; [1]Dipartimento di Meccanica, Politecnico di Milano, Via La Masa 1, 20156 Milano, [2]BAM, Berlin, Germany; [3]SKB, Oskarshamn, Sweden

---For inspection of thick-walled copper canisters (50mm) for final disposal of spent nuclear fuel in Sweden, ultrasonic inspection using phased array technique (PAUT) is applied. Based on the fact that thick-walled copper not commonly is used as construction material, previous experience on PAUT for this type of application is limited. The paper presents the progress in understanding the amplitudes and attenuation changes acting on the PAUT inspection of the copper canisters. Previous studies showed the existence of a low pass filtering effect, and a heterogeneous grain size distribution along the depth, thus affecting both the detectability of defects and their POD determination. Consequently, the difference between the first and second back wall echoes were not sufficient to determine the local attenuation (within the inspection range), which affects the signal response for each individual defect. Experimental evaluation of structural attenuation was carried out onto step-wedge samples cut from full-size, extruded and pierced & drawn, copper canisters. Effective attenuation values has been implemented in numerical simulation to achieve a Multi Parameter POD and to formulate a Model Assisted POD through a Monte-Carlo extraction model.

9:30 AM

Model-based POD Study of Manual Ultrasound Inspection and Sensitivity Analysis Using Metamodel

---**Guillemette Ribay**, Xavier Artusi and Frédéric Jenson, CEA LIST Bat 565 PC120, 91191 Gif sur Yvette, France; Christopher Reece, EDF - DIN-CEIDRE, Etudes-ETC,2 rue Ampère,93206 Saint Denis, France; Pierre-Emile Lhuillier, Departement MMC, EDF R&D, Sites des Renardieres, 77818 Moret-sur-Loing, France

---The reliability of NDE can be quantified by using the Probabibility of Detection (POD) approach. Former studies have shown the potential of the model-assisted POD (MAPOD) approach to replace expensive experimental determination of POD curves [1,2]. In this paper, we make use of CIVA software to determine POD curves for a manual ultrasonic inspection of a heavy component, for which a whole experimental POD campaign was not available. The influential parameters were determined by expert analysis. The semi-analytical models used in CIVA for wave propagation and beam-defect interaction have been validated in the range of variation of the influential parameters by comparison with finite element modelling (Athena). The POD curves are computed for « hit/miss » and « â versus a » analysis. The verification of Berens hypothesis is evaluated by statistical tools. A sensitivity study is performed to measure the relative influence of parameters on the defect response amplitude variance, using the Sobol sensitivity index [3,4]. A meta-model is also built to reduce computing cost and enhance the precision of estimated index.

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9:50 AM

POD Evaluation Using Simulation: Progress, Practice and Perspectives

---**Nicolas Dominguez**, Airbus Group Innovations, Toulouse, France; Frederic Reverdy, CEA-LIST, Toulouse, France

---NDT performances evaluation in the aeronautic industry is made by estimating Probability of Detection (POD). It is a statistical estimation of the capability of a given NDT procedure to detect defects as a function of their size. The accuracy of the statistical estimation is directly linked the quality and quantity of collected data. The more data and the more realistic they are, the better the POD estimation. This practical production of data may have very high cost, sometimes obliging to decrease either the quantity or the quality (realistic) of data, or even both. In the last decade MAPOD and simulation-based POD approaches have emerged and been used for concept demonstration as a solution to decrease the cost of evaluating POD. Today tools are available to support these studies and are used in industrial laboratories.

This paper reviews some examples of POD evaluation using simulation, describes the actual practice of the tools in the European aeronautical context and also draws some limits and perspectives for a future wider application of the simulation helped POD approach.

10:30 AM

Advanced Reliability Methods – A Review

David S. Forsyth, TRI/Austin, 9225 Bee Caves Road, Austin, TX USA 78733

The tools available for nondestructive testing, risk assessment, and engineering design continue to evolve and to drive the need for assessing the reliability of NDT. In this presentation, we will review how the NDT community has developed methods to assess reliability and discuss the state of the art and gaps in the state of the art.

Engineering design, particularly the developments in understanding fatigue and fracture, have evolved to include NDT as one of the necessary elements in ensuring safety throughout the life cycle. Given the large number of variables that can affect the performance of an NDT technique and its application, empirical methods have been developed that can provide estimates of the Probability of Detection (POD) of damage as a function of damage size. The United States Air Force handbook MIL-HDBK-1823 is a commonly used reference for POD estimation. The underlying statistical methods were developed from an examination of eddy current inspection of aircraft engine parts for fatigue cracks. Relationships between the amplitude of the ET signal and the crack size were developed into POD estimates. For NDT situations that can fit into this paradigm, these methods are still relevant and satisfy many requirements.

There are a number of challenges to the current practices for POD assessment. Some NDT methods, especially those that are image-based, may not provide a simple relationship between a scalar NDT response and a damage size. Some damage types are not easily characterized by a single scalar metric. Other sensing paradigms, such as structural health monitoring, could theoretically replace NDT but require a POD estimate. And the cost of performing large empirical studies to estimate POD can be prohibitive.

The response of the research community has been to develop new methods that can be used to generate the same information, POD, in a form that can be used by engineering designers. We will highlight approaches to image-based data and complex defects, Model Assisted POD estimation, and Bayesian methods for combining information. We will also review the relationship of the POD estimate, confidence bounds, tolerance bounds, and risk assessment.

11:10 AM

How Much Information Do We Need? A Reflection on the Correct Use of Real Defects in POD Evaluations

---**Daniel Kanzler**[1] and Christina Müller[1], [1]BAM Federal Institute for Materials Research and Testing, Berlin, Germany

---To evaluate the capability of an NDT system, the “truth” of the used defects is essential. But what exactly is the truth of a real defect? And how much information is usable for the study? This paper gives an overview about an advanced use of multiple metallographic cuts for the POD evaluation. For this purpose an approach was developed, in which information from the metallographic studies are reconstructed and weighted to gain essential information about real defects and about which information is important for the detection with radiographic testing equipment. Furthermore, how additional knowledge from simulations and artificial defects can be used to gain additional certainty for the result of the evaluation will be discussed. This methodology was developed for the evaluation of the digital radiographic testing system used to inspect electron-beam welds, i.e. one of the considered options to seal copper canisters used for the final disposal of spent nuclear fuel in Finland.

11:30 AM

Improving the Reliability of POD Curves in NDI Methods Using a Bayesian Inversion Approach for Uncertainty Quantification

---**Anis Ben** Abdessalem, Frédéric Jenson, Pierre Calmon, CEA LIST, 91191 Gif-sur-Yvette, France

---This contribution provides an overview of the possible advantages of adopting a Bayesian inversion approach to uncertainty quantification in nondestructive inspection methods. In such problem, the uncertainty associated to the random parameters is not always known and needs to be characterized from scattering signal measurements. The uncertainties may then correctly propagated in order to determine a reliable probability of detection curve. To this end, we establish a general Bayesian framework based on a non-parametric maximum likelihood function formulation and some priors from expert knowledge. However, the presented inverse problem is time-consuming and computationally intensive. To cope with this difficulty, we replace the real model by a surrogate one in order to speed-up the model evaluation and to make the problem to be computationally feasible for implementation. The least squares support vector regression is adopted as metamodelling technique due to its robustness to deal with non- linear problems. We demonstrate and validate the usefulness of this powerful methodology through the control of tube with enclosed defect using ultrasonic inspection method.

11:50 AM

Development of Image Detection Criteria for Digital Data

---**Joe Gray**[1] and Irving Gray[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]NDE Technologies, Inc., 1785 Sourwood Place, Charlottesville, VA 22911-7425

---The emergence of image data in NDE and especially the general adoption of digital detectors in x-ray imaging offer opportunities for routinely detecting low contrast to noise signals(CNR) in images. Detectability criteria for 2D or image data needs to be developed to take advantage of this improvement in detector performance. This is particularly so in data sets where a large number of pixels make up the image of the defect. As the number of pixels contributing to the defect signature increases lower and lower contrasts can be detected. Indeed as we move from point measurements where a common consensus of adequate signal to noise ratios (SNR) are 3:1, we see that in multiple pixel defect images that the CNR can reduce to less than 1:1 while still maintaining detectability of defects. We propose an image detection criterion for image data as a function of CNR and the number of pixels involved in the measurement. We will further discuss how small amplitude features in an image significantly increase the limit of detection of a defect signal. As an example of this camouflage, we point to diffraction mottling that can occur in large grained materials such as nickel and titanium. The key to determining the detectability limit for an inspection is the detection criteria used. Traditionally this is supplied by a human inspector or a threshold for the defect contrast. We will discuss the use of statistical tests on the low CNR signals and an additional detection criteria capturing more closely human eye-mind performance. We will utilize the availability of accurate NDE simulators to estimate in limits of detectability and the evaluation of optimal inspection parameters needed in the design of POD studies. Finally we will present experimental results of the model validation and discuss the limitations of both the simulation and experimental approaches to POD determinations.

Session 11

SESSION 11
STUDENT POSTERS
1:30 PM – 3:10 PM
Nicollet AB

NOTE: All Posters will be displayed continuously Monday through Thursday in Nicollet AB. During the Tuesday and Thursday afternoon poster sessions, the individual presenters will be on hand to answer questions.

EMAT for Omni-Directional Shear-Horizontal Guided Wave Generation in a Plate
---**Hong Min Seung**, Chung Il Park, and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering and Institute of Advanced Machinery and Design, South Korea

Evaluating an SH Wave EMAT System for Pipeline Screening and Extending into Quantitative Defect Measurements
---**M. Clough** and S. Dixon, University of Warwick, Physics Department, Gibbet Hill Road, Coventry CV4 7AL, United Kingdom; M. Fleming and M. Stone, Sonomatic Ltd., Dornoch House, The Links, Birchwood, Warrington, Cheshire, WA3 7PB, United Kingdom

Scattering of High Order Guided Wave Modes Around a Through Thickness Circular Hole
---**Christophe Travaglini**[1], Christophe Bescond[2], Desmartonne Ramos Franca[1], Silvio E. Kruger[2], Martin Viens[1], and Pierre Belanger[1]; [1]Département de Génie Mécanique École de Technologie Supérieure, 1100 rue Notre-Dame Quest, Montréal (Québec), H3C 1K3, Canada; [2]Conseil National de Recherches Canada, 75 boulevard de Mortagne, Boucherville (Québec), J4B 6Y4, Canada

Experimental Characterization of Early-Stage Stress Corrosion Cracking Using Nonlinear Ultrasound
---**Alexander J. Lakocy**, Jin-Yeon Kim, James J. Wall, and Laurence J. Jacobs, 790 Atlantic Drive NW, Mason 2132, Atlanta, GA 30332-0355

Energy Backscattering Approach to Characterize Cracking Damage in Concrete Using Fully Contactless Ultrasonic
---**Suyun Ham,** John S. Popovics, and Michael L. Oelze, The University of Illinois at Urbana-Champaign, 342 Paddock Drive West, Savoy, IL 61874

Guided Waves Propagating a Helical Structure
---**Kousuke Kanda** and Toshihiko Sugiura, Keio University, School of Integrated Design Engineering, 3-14-1 Hiyoshi Kouhokuku Yokohama-city, Kanagawa, Japan

Feature Guided Waves (FGW) in Fiber Reinforced Composite Plates with 90° Transverse Bends
---**X. Yu**[1], P. Manogharan[2], M. Ratassepp[1], Z. Fan[1], and P. Rajagopal[2], [1]Nanyang Technological University, School of Mechanical and Aerospace Engineering, 50 Nanyang Avenue, Singapore 639798; [2]Indian Institute of Technology Madras, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai-600036, Tamil Nadu, India

SAFE-3D Analysis of a Piezoelectric Transducer to Excite Guided Waves in a Rail Web
---Dineo A. Ramatlo**[1,2], Philip W. Loveday[1], Craig S. Long[1], and Daniel N. Wilke[2], [1]CSIR Materials Science and Manufacturing; [2]Department of Mechanical and Aeronautical Engineering, University of Pretoria**

Development of Nonlinear Ultrasonic Techniques to Assess Microstructural Damage in 1% Fe-Cu Steel
---**Katherine Scott**[1], Laurence Jacobs[1,2], Jin-Yeon Kim[2], and James Wall[1,3], [1]G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332; [2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; [3]Electric Power Research Institute, Charlotte, NC 28262

Development of a Low Frequency Shear Horizontal Piezoelectric Transducer for the Generation of Plane SH Waves
---**Guillaume Boivin**, Martin Viens, and Pierre Bélanger, Department of Mechanical Engineering, École de Technologie Supérieure, 1100, rue Notre-Dame Quest, Montréal (Québec), H3C 1K3, Canada

Measurement of Attenuation Coefficients of the Fundamental and Second Harmonic Waves in Water
---**Shuzeng Zhang**[1], Hyunjo Jeong[2], Sungjong Cho[2], and Xiongbing Li[1], [1]Central South University, School of Traffic and Transportation Engineering, Changsha, Hunan, 410075, China; [2]Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jeonbuk 570-749, Republic of Korea

Rapid Lamb Wave-Based Subwavelength Damage Imaging Using the DORT-MUSIC Technique
---**Jiaze He**[1,2] and Fuh-Gwo Yuan[1,2], [1]National Institute of Aerospace, Center for Integrated Structural Health Management, Hampton, VA 23666; [2]North Carolina State University, Department of Mechanical and Aerospace Engineering, Raleigh, NC 27695

Voronoi Based Microstructure Modeling for Elastic Wave Propagation
---**S. Shivaprasad**[1], Krishnan Balasubramaniam[1], and C. V. Krishnamurthy[2], [1]Indian Institute of Technology, Madras, Centre for Non-Destructive Evaluation, Department of Mechanical Engineering, Chennai, India; [2]Indian Institute of Technology, Madras, Department of Physics, Chennai, India

Anomaly Detection in Radiographic Images of Carbon Fiber via Crosshatch Regression
---**Colin Lockard**, Willam. P. Winfree, and Eric Burke, NASA Langley Research Center, Hampton, VA 23681; Almudena Konrad, Mills College, Oakland, CA 94613; Raymond McCollum, Booz Allen Hamilton, Hampton, VA 23681

Learning to Identify Delaminations in Composite Materials Using Convolutional Neural Networks
---**Daniel Sammons**, NASA Langley Research Center, Hampton, VA 23681 and Department of Computer Science, Old Dominion University, Norfolk, VA 23529; William P. Winfree and Eric Burke, NASA Langley Research Center, Hampton, VA 23681

Effect of Fill Conditions on Bulk Wave Scattering from a Through-Hole
---Joseph W. Kummer**, Alexander J. Dawson, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250**

A Study on Dispersion Characteristics of Leaky Rayleigh Wave on the Layered Thin Film Structure by Loading and Stiffness Effect
---**Byung-seok Jo**, Tae-sung Park, Seung-bum Cho, and Ik-keun Park, Seoul National University of Science and Technology(Seoultech), Department of Mechanical and Automotive Engineering, Seoul, Korea

Electromagnetic Non-Destructive Technique for Duplex Stainless Steel Characterization
---**João V. G. Rocha**, Cesar G. Camerini, and Gabriela R. Pereira, Laboratory of Non-Destructive Testing, Corrosion and Welding, Federal University of Rio de Janeiro – RJ, Brazil

Second Harmonic Rayleigh Wave Detection Using a Heterodyne Laser Interferometer
---**Aulon Bajrami**, David Torello, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, Atlanta, GA 30318

3D Modelling of Air-Coupled Detection of Nonlinear Rayleigh Surface Waves
---**Matthias P. Uhrig**, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, 1059B Terrell St., NW, Atlanta, GA 30318

Finite Element Simulation of Higher Harmonic Rayleigh Wave Generation Due to Interaction with Defects
---**Tobias Oberhardt**, Jin-Yeon Kim, Jianmin Qu, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318

Precision Measurement of Crack Closure State with Vibrothermography
---**Bryan Schiefelbein**, Ashraf F. Bastawros, and Stephen D. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50014

Comparison of Ultrasonic Nonlinear Parameters Measured by PZT and $LiNbO_3$ Transducer
---**Jongbeom Kim**[1], Kyoung-Jun Lee[1], Ju-ho Lee[1], and Kyung-Young Jhang[2], [1]Hanyang University, Department of Mechanical Convergence Engineering, Seoul 133-791, Republic of Korea; [2]Hanyang University, School of Mechanical Engineering, Seoul 133-791, Republic of Korea

Volumetric Measurement of Residual Stress Using High Energy X-Ray Diffraction
---**R. Whitesell, A. McKenna**, S. Wendt, and J. Gray, Iowa State Univesity, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Interface Wave Propagation Analysis for the Nuclear Reactor Nozzle Weld
---**Junpil Park**[1], Jaesun Lee[1], Kyung-Young Jhang[2] and Younho Cho[3], [1]Pusan National University, Graduate School, School of Mechanical Engineering, Busan, South Korea, 609-735; [2]Hanyang University, School of Mechanical Engineering, Seoul, South of Korea, 133-791; [3]Pusan National University, School of Mechanical Engineering, Busan, South Korea, 609-735

Optimization of X-ray CT data acquisition for the inversion of material characteristics of fibre reinforced composites
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EMAT for Omni-Directional Shear-Horizontal Guided Wave Generation in a Plate

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---The rapid inspection of large plate-like structures based on omni-directional shear-horizontal (SH) guided wave transducers can be very useful in the fields of non-destructive evaluation (NDE) and structural health monitoring (SHM) because of the non-dispersive property of the fundamental SH wave mode (SH0). Recently, an omni-directional SH wave transducer using a thin magnetostrictive patch tightly bonded onto a plate by epoxy resin was developed [1]. However, the disadvantage of the transducer is that it always requires the bonding of a magnetostrictive patch onto a test specimen. As a means to overcome this disadvantage, we propose the first realization of an electromagnetic acoustic transducer (EMAT) that can generate and measure omni-directional SH waves in a metallic plate without any physical contact [2]. Although the EMAT principle is well-known, there is no omni-directional SH wave EMAT so far. The key in this development is in the EMAT configuration. The developed omni-directional SH EMAT consists of a pair of ring-type permanent magnets and a specially-wound coil unlike other conventional EMATs. After how omni-directional SH waves can be generated by the proposed EMAT configuration is presented, its performance is checked by the finite element analyses and the experiments. A method to enhance the sensitivity of the transducer is also suggested by using a ferromagnetic yoke that is installed on the magnets. The influence of the yoke is carefully studied.---This research was supported by the National Research Foundation of Korea (NRF) grant (No. 2014M3A6B3063711 and No. 2015021967) funded by the Korean Ministry of Science, ICT & Future Planning contracted through Institute of Advanced Machinery and Design at Seoul National University and Brain Korea 21 Plus Project in 2015.

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Evaluating an SH Wave EMAT System for Pipeline Screening and Extending into Quantitative Defect Measurements

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---Guided waves are now commonly used in industrial NDT for locating corrosion in pipelines in the form of wall thinning. Shear Horizontal waves generated by EMATs are used in a screening arrangement to locate and size corrosion in terms of axial extent and circumferential positioning. This is facilitated by propagating SH waves circumferentially around the pipeline whilst moving a scanning rig axially, keeping transducer separation constant. This arrangement is preferential in that it can operate through thin(up to 1mm) coatings and does not require full access to the pipe's circumference and is useful for detecting corrosion in difficult to access regions such as below pipe supports and in subsea applications. The performance of the system in terms of screening capability and the possibilities of extension into more quantitative measures are assessed. The behavior of different wave modes as they interact with defects is investigated via experimental measurements on artificially induced corrosion patches and measurements on samples with in service corrosion. Measurement of the axial extent of corrosion patches, circumferential positioning and a range of possible remaining thickness is assessed. Finite element modelling of SH mode interaction with defects is used to identify what happens to different wave modes when they interact with defects in terms of reflection, diffraction and mode conversion.---The work is funded by EPSRC through an EngD studentship from the Research Centre for Non Destructive Evaluation and supported by Sonomatic Ltd.

Scattering of High Order Guided Wave Modes around a Through Thickness Circular Hole

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---Ultrasonic guided waves have the ability to propagate long distances with minimal attenuation, this makes them particularly interesting in structural health monitoring (SHM) applications. Using the baseline subtraction approach, the signal from a defect free structure is compared to the actual monitoring signal to detect and locate defects. There are many scientific publications on low frequencies guided waves for SHM purposes and the interaction between guided wave fundamental modes and defects is also well documented. There is however a very limited number of studies on high order modes. High frequency guided waves may enable the detection of smaller cracks relative to conventional low frequency guided waves SHM. The main difficulty at high frequency is the existence of several modes with different velocities. This study investigates the scattering of high order guided wave modes around a through-thickness hole with a view to develop a highly sensitive SHM method. A 3D finite element model of a 600 mm × 600 mm × 1.6 mm aluminum plate was used to determine the scattering of cracks on the circumference of a through-thickness hole in the middle of the plate. Crack properties such as orientation, length and depth were studied. A subset of the finite element simulations were validated against experimental results. The experimental setup comprised a film type PZT actuator bonded on the side of the plate and a laser interferometer detector. An input signal centered at 4 MHz was used in all simulations and experiments.---The authors would like to acknowledge the Consortium for Research and Innovation in Aerospace in Québec, the NRC program AERO21 and our industrial partners, Bombardier and L3-MAS, for their generous support.

Experimental Characterization of Early-Stage Stress Corrosion Cracking Using Nonlinear Ultrasound

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---Corrosion of materials cost over 3% of the United States' GDP in 2013, amounting to approximately $500 billion. In many corrosive industrial environments, this issue is further complicated by the introduction of mechanical stress. Often, this combination leads to stress corrosion cracking (SCC), a damage mechanism which typically affects austenitic stainless steels in the heat-affected zone (HAZ) near a weld. This research uses nonlinear ultrasound (NLU) in order to characterize the microstructural changes in the HAZ of 304 stainless steel, a common industrial metal, prior to any exposure to chemical corrosion agents. NLU measurements using Rayleigh surface waves demonstrate that the acoustic nonlinearity parameter f3 shows significant sensitivity to these microstructural changes, indicating that NLU can be used to evaluate susceptibility to stress corrosion cracking before any measureable damage has occurred.

Energy Backscattering Approach to Characterize Cracking Damage in Concrete Using Fully Contactless Ultrasonic

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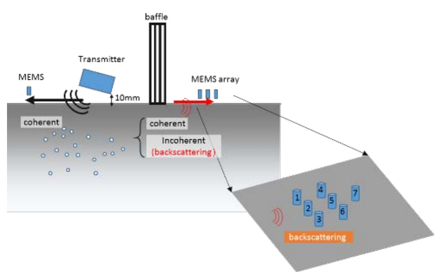
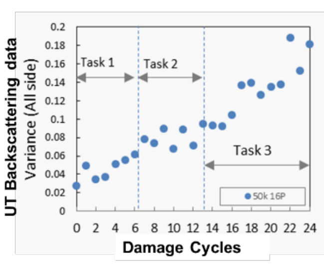
---Contactless, air-coupled ultrasonic techniques offer much promise for rapid non-destructive evaluation (NDE) for large concrete structures. Contactless ultrasonic surface wave measurement is especially interesting for situations where access to only one surface of a structure is provided. Here we describe a recent research effort that applies contactless ultrasonic surface waves to concrete in order to determine the sensitivity of such measurements to the presence of distributed cracking damage in the concrete. The contactless sensor set, controlled scanning platform, signal processing schemes, and testing samples used in a set of experimental tests are described. The concrete test samples contain distributed cracking across a range of cracking extent, ranging from low to high crack volume density. Finite element simulation analyses and results from the experiments revealed that forward propagating surface wave group velocity and pulse attenuation (i.e. forward scattering) data were relatively insensitive to the presence of distributed cracking in concrete. On the other hand, backscattered surface wave energy measurements were much more sensitive to the presence of cracking. The backscattered energy was extracted from the total obtained signal using two different approaches: a time-domain subtraction approach and a spectral variance analysis approach. Both approaches provided consistent results that track well to internal cracking damage extent, comparable to standard resonance tests on companion samples. A large set of backscatter data collected across a sample illustrate the potential to use such data to image concrete surface and to identify localized regions of damage. The backscatter image results were compared with infrared thermograph and optical surface images of the sample.



Testing configuration



UT Backscattering data

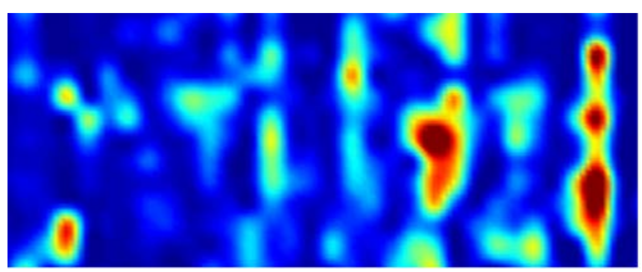


Image of local damage by backscattering process

Guided Waves Propagating a Helical Structure

---**Kousuke Kanda** and Toshihiko Sugiura, Keio University, School of Integrated Design Engienering, 3-14-1 Hiyoshi Kouhokuku Yokohama-city, Kanagawa, Japan

---Guided waves can propagate with low attenuation along waveguides such as long pipes and rails. Therefore, using guided waves is ideal for nondestructive testing, especially of wire-ropes that requires long time by conventional methods of testing. But the complicated twisted structure of a wire-rope makes practical use of guided waves difficult. Also, guided waves have dispersibility which changes propagation velocities by input frequencies. Its characteristics are important for identifying where there is a crack. In general, dispersion curves for an arbitrarily structure are often obtained by the semi-analytical finite element method (SFE). SAFE is a numerical approach used to study uniform guided waves propagating through an arbitrary cross section. In this study, however, the authors expanded the theory of cylindrical guided waves to helical structures. Adding an effect of a curvature and an effect of torsion to the theory of cylindrical guided waves, we succeeded in analytically calculating dispersion curves for helical structures, as shown in Fig. 1.

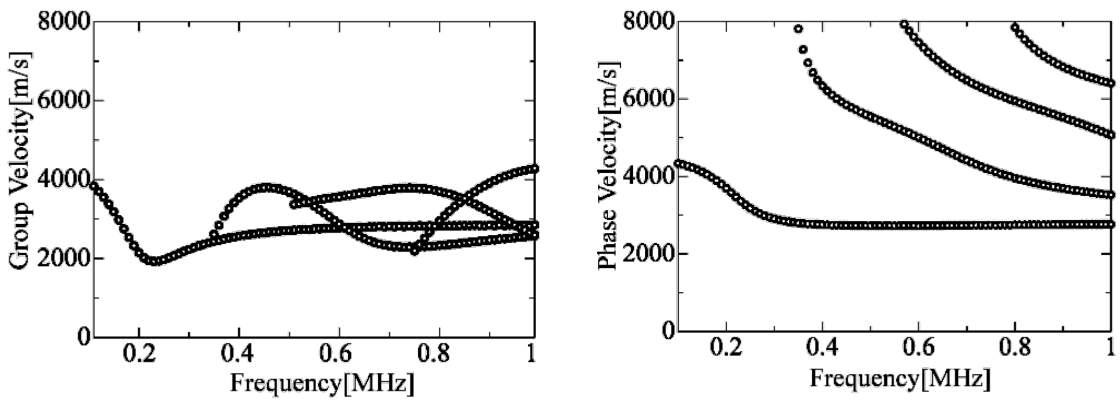


Figure 1. Dispersion curves in helical structure with radius 10mm (L-mode).

Feature Guided Waves (FGW) in Fiber Reinforced Composite Plates with 90° Transverse Bends

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---Fiber reinforced composite materials have been increasingly used in high performance structures such as aircraft and large wind turbine blades, because of their high strength to weight ratio, good stiffness properties and inherent corrosion resistance. This brings new challenges in the manufacturing of specific components as well as for the non-destructive testing (NDT) of the structure throughout its service life. For instance, 90° composite bends are common in aerospace industry, and due to stress concentration the bend region is prone to defects such as delamination. Current techniques to inspect these bends require scanning ultrasonic probes with selected wedge over the whole region of interest, which is time consuming and tedious. This paper explores the feasibility of using feature guided waves (FGW) for rapid screening of 90° composite laminated bends. This idea comes from the authors' previous studies of feature guiding phenomena in metallic bends, which suggest the presence of low dispersive and low attenuative bend-guided waves and their capabilities of focusing the energy along the bend. In this new study, behaviors of the bend-guided wave in the anisotropic composite material are investigated through modal studies using the Semi-Analytical Finite Element (SAFE) method, while 3D finite element (FE) simulations are performed to visualize the results and also to obtain cross validation. To understand the influence of anisotropy, three-dimensional dispersion curves of the guided modes are obtained, showing the dependence of the phase and group velocity with the frequency and fiber orientation. Proper guided modes are then identified with energy concentrated in laminated bends, limiting energy radiation into adjacent plates and thus achieving increased inspection length. Finally, preliminary experiments are also carried out to validate the modeling results.

SAFE-3D Analysis of a Piezoelectric Transducer to Excite Guided Waves in a Rail Web

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---Our existing Ultrasonic Broken Rail Detection system detects complete breaks and primarily uses a propagating mode with energy concentrated in the head of the rail [1]. Previous experimental studies have demonstrated that the head mode, depicted in Figure 1(a), is capable of detecting weld reflections at long distances. Based on numerical work, we feel that we would be able to detect cracks in the rail head. Investigations are underway to extend the system to look for damage before a complete break occurs. Exploiting a mode with energy concentrated in the web of the rail, depicted in Figure 1(b), would allow us to effectively detect defects in the web of the rail and could also help to distinguish between reflections from welds and cracks. In this paper, we will demonstrate the analysis of a piezoelectric transducer attached to the rail web. The forced response at different frequencies is computed by the Semi-Analytical Finite Element (SAFE) method [2] and compared to a full three- dimensional finite element method using ABAQUS. The SAFE method only requires the rail track cross-section to be meshed using two-dimensional elements. The ABAQUS model in turn requires a full three-dimensional discretization of the rail track. The SAFE approach can yield poor predictions at cut-on frequencies associated with other modes in the rail. Problematic frequencies are identified and a suitable frequency range identified for transducer design. The forced response results of the two methods were found to be in good agreement with each other. We then use a previously developed method to analyze a practical transducer over the selected frequency range.

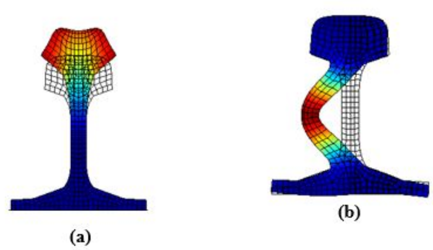

Figure 1. Displacement of the rail cross-section for the head mode (a) and web mode (b).

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Development of Nonlinear Ultrasonic Techniques to Assess Microstructural Damage in 1% Fe-Cu Steel

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---The US fleet of operating light water nuclear power reactors has entered the period of life extension, and components will see more neutron exposure and duty cycles than were originally anticipated. It is therefore critical to develop methods of detecting microstructural damage that can occur in these reactor pressure vessels (RPV) due to radiation. During irradiation, there are several phenomena that can cause the microstructural damage in ferritic RPV steels that leads to embrittlement. One of these is the formation of copper clusters. This research considers a surrogate specimen, 1% Fe-Cu steel subjected to different heat treatment holding times to mimic copper cluster formation, and then tracks the damage with the generation of the second harmonic in Rayleigh surface waves. Recent studies have shown that nonlinear ultrasound (NLU) is sensitive to microstructural changes in materials [1,2,3]. The specimens used in this research were heated treated for varying amounts of holding times using the same schedule that was used by Park and fellow researchers at KAERI [4]. This variation in heat treatment times simulates varying amounts of radiation damage by the formation of copper precipitates. In order to characterize the amount of copper precipitates that have formed in each of these specimens, this research measures the acoustic nonlinearity parameter, β. Rayleigh surface waves are generated with a wedge transducer, and an air coupled transducer is used for detection. As the Rayleigh wave propagates along the surface, the amplitudes of the first and second harmonics are measured and used to obtain the value of β. The NLU results are used to correlate β with the amount (size and distribution) of copper precipitates present. These results demonstrate that β is sensitive to the copper precipitates present and has the potential to track radiation damage that occurs in RPV steels.

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Development of a Low Frequency Shear Horizontal Piezoelectric Transducer for the Generation of Plane SH Waves

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---The shear horizontal guided wave fundamental mode (SH0) has the particularity of being the only non-dispersive plate guided wave mode. This characteristic makes this ultrasonic guided wave mode very attractive in non-destructive testing, facilitating the signal processing for long-range inspections. It is, however, difficult to generate only a single guided wave mode when using piezoelectric transduction. This work aims to develop a piezoelectric transducer capable of generating a virtually pure plane zeroth order shear horizontal wave. The chosen material was the PZT-5H for its dominant d_{15} piezoelectric constant which makes it a perfect candidate for SH-wave generation. The transducer dimensions were optimised using an analytical model based on the Huygens's principle of superposition [1] and the dipole pattern of a shear point source [2]. A 3D multiphysics finite element model was then used to validate the analytical model results. Experimental validation was finally conducted with a laser Doppler vibrometer (LDV) system. Excellent agreement between the analytical model, finite element model and experimental validation was seen. The finite element directivity pattern of the transducer for every excited zeroth order guided waves modes is presented in figure 1. The results showed that it is possible to generate a plane SH-wave wider than twice the transducer surface.---The work was supported by the Consortium for Research and Innovation in Aerospace in Québec (CRIAQ) including Bombardier Aerospace, L-3 MAS and NRC. The authors would also like to acknowledge the generous support of the University of Sherbrooke GAUS research group.

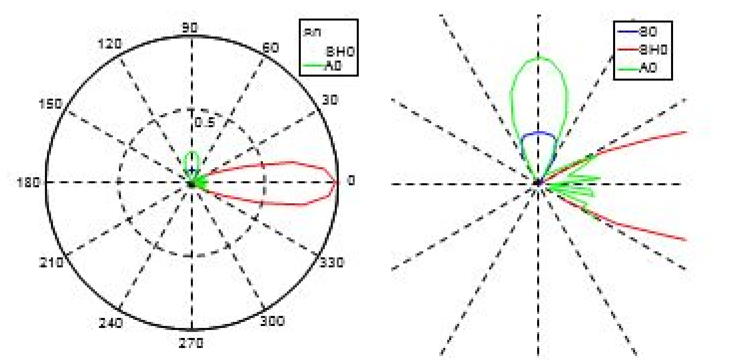

Figure 1. FEM Directivity pattern, (a) Original, (b) 4x zoom.

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Measurement of Attenuation Coefficients of the Fundamental and Second Harmonic Waves in Water

---**Shuzeng Zhang**[1], Hyunjo Jeong[2], Sungjong Cho[2], and Xiongbing Li[1], [1]Central South University, School of Traffic and Transportation Engineering, Changsha, Hunan, 410075, China; [2]Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jeonbuk 570-749, Republic of Korea

---Attenuation corrections in nonlinear acoustics play an important role in the study of nonlinear fluids, biomedical imaging, or solid material characterization. The measurement of attenuation coefficients in a nonlinear regime is not easy because they depend on the source pressure and requires accurate diffraction corrections. In this work, the attenuation coefficients of the fundamental and second harmonic waves which come from the absorption of water are measured in nonlinear ultrasonic experiments. Based on the quasilinear theory of the KZK equation, the nonlinear sound field equations are derived and the diffraction correction terms are extracted. The measured sound pressure amplitudes are adjusted first for diffraction corrections in order to reduce the impact on the measurement of attenuation coefficients from diffractions. The attenuation coefficients of the fundamental and second harmonics are calculated precisely from a nonlinear least squares curve-fitting process of the experiment data. The results show that attenuation coefficients in a nonlinear condition depend on both frequency and source pressure, which are much different from a linear regime. In a relatively lower drive pressure, the attenuation coefficients increase linearly with frequency. However, they present the characteristic of nonlinear growth in a high drive pressure. As the diffraction corrections are obtained based on the quasilinear theory, it is important to use an appropriate source pressure for accurate attenuation measurements.---This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (Grant No. 2013-R1A2A2A01016042), and by the National Natural Science Foundation of China (Grant Nos. 61271356, 51205031).

Rapid Lamb Wave-Based Subwavelength Damage Imaging Using the DORT-MUSIC Technique

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---A Lamb wave-based, subwavelength imaging algorithm is developed for damage imaging in large-scale, plate-like structures based on a decomposition of the time-reversal operator (DORT) method combined with the multiple signal classification (MUSIC) algorithm. In this study, a rapid non-contact scanning system was proposed to image an aluminum plate using a piezoelectric linear array for actuation and a laser Doppler vibrometer (LDV) line-scan for sensing. The physics of wave propagation, reflection, and scattering that underlies the response matrix $\boldsymbol{K}$ in the DORT method is mathematically formulated in the context of guided waves. Singular value decomposition (SVD) is then employed to decompose the experimentally measured response matrix into three matrices, detailing the incident wave propagation from the linear actuator array, reflection from the damage, and followed by scattering waves toward the linear sensing array for each site of small damage. The SVD and MUSIC-based imaging condition enable quantifying the damage severity by a 'reflectivity' parameter and super-resolution imaging. With the flexibility of this scanning system, a considerably large area can be imaged using lower frequency Lamb waves with limited line-scans. The experimental results showed that the hardware system with a signal processing tool such as the DORT-MUSIC (TR-MUSIC) imaging technique can provide rapid, highly accurate imaging results as well as damage quantification with unknown material properties.

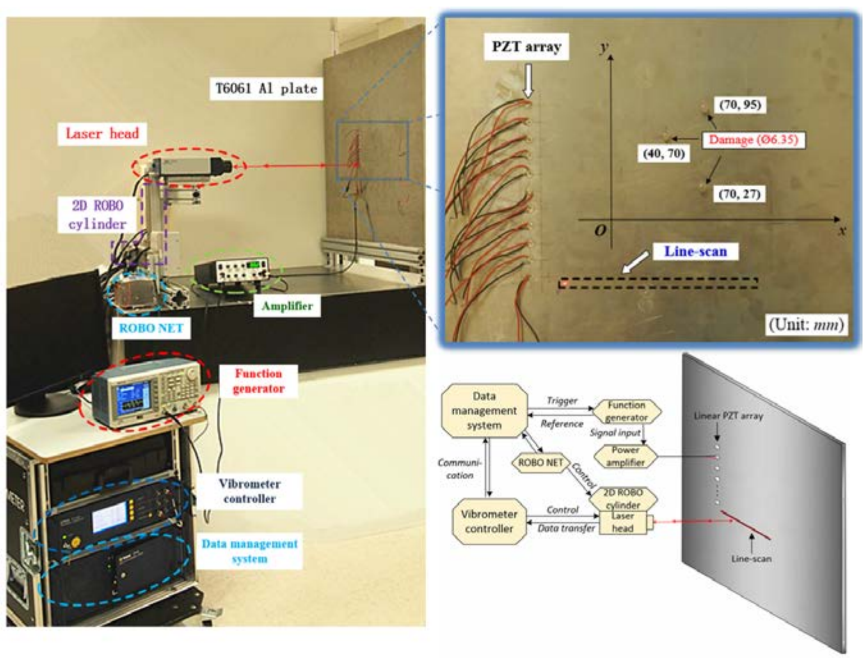

Figure 1. Experimental setup for the hybrid PZT/LDV scanning system for subwavelength imaging.

Voronoi Based Microstructure Modeling for Elastic Wave Propagation

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---Ultrasonic testing of materials is affected by microstructural parameters like grain size and texture. When a beam of ultrasound propagates through a polycrystalline material, acoustic energy gets scattered at grain interfaces due to the difference in acoustic impedances between different grains. This scattering results in loss of acoustic energy from the beam, resulting in energy attenuation. Loss in energy can significantly affect the ability to detect defects while performing experiments. It is necessary to have a better understanding of effects of elastic anisotropy, grain size and grain-size distribution, and the complexity of the microstructure which govern the interaction of ultrasound beam with the microstructure. A two dimensional finite element based microstructural model is constructed using Voronoi tessellation for representing polycrystalline material. COMSOL™ with MATLAB™ environment is used for implementation of the finite element simulations. The role of cell size distributions, effects of average cell size on scattering of long and short wavelength elastic waves, and influence of orientational averaging on elastic wave propagation in copper and stainless steel materials are described.

Anomaly Detection in Radiographic Images of Carbon Fiber via Crosshatch Regression

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---An algorithm is proposed for the automated identification of anomalies in computed tomography (CT) scan images of carbon fiber. At present, the analysis of these scans requires labor intensive visual inspection. The approach adopted is labeled crosshatch regression, where an image is divided into a series of one-dimensional traces, each representing a single line of pixels in either the x- or y-direction. This is similar to a technique that has been previously been applied to images of welding defects1. A polynomial robust regression model is fitted to each trace and a prediction interval is calculated around the model. Points falling outside the prediction interval are designated as outliers. A trough identification technique is used to determine the edges of the anomalous area. If the pixel was identified as an outlier in both an x- and a y-signals, it is considered as an outlier for the image as a whole. Three crosshatch regression runs are applied successively to the image, each using different parameters. The first run identifies all potentially anomalous regions in the image. The second run identifies only very obvious outliers. The third run removes the outliers identified in the second run from the image and is then able to identify regions exhibiting more subtle differences from the norm. To be considered anomalous, pixels must be identified as outliers in the first run as well as in either the second or third run. A threshold is instituted based on the sum of residuals of each identified region of interest to eliminate noise. In a set of simulated images representing various sizes and intensities of delaminations, the algorithm successfully identified the presence of 92% of anomalies, while generating zero false positive regions. The regions identified matched the true anomalies with a pixel-level precision of 78% and recall of 89%. Average root mean square deviation of the boundaries was 11.2 pixels. A comparison of the method's results with an expert's assessment will be included. Future work will attempt to further characterize anomalous regions using machine learning techniques similar to work previously done on images of welding defects.2---This work was jointly funded by NASA Langley Research Center's Advanced Composites Program and Big Data Analytics and Machine Intelligence program.

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Learning to Identify Delaminations in Composite Materials Using Convolutional Neural Networks

---**Daniel Sammons**, NASA Langley Research Center, Hampton, VA 23681 and Department of Computer Science, Old Dominion University, Norfolk, VA 23529; William P. Winfree and Eric Burke, NASA Langley Research Center, Hampton, VA 23681

---Inspired by the recent success of deep learning applied to machine perception problems, this work utilizes convolutional neural networks to automate the process of identifying and segmenting delaminations in computed tomography (CT) scans of composite materials. Well known for their ability to learn hierarchies of features in image recognition tasks, convolutional neural networks have previously proven that they are capable of learning the intricacies of medical imagery by segmenting neuronal structures in electron microscopy images and by identifying cells in mitosis in breast cancer histology images [1, 2]. Following a similar framework, a convolutional neural network can be trained to classify pixels in images of composite materials as either normal or delaminated. In particular, a small window around each pixel is treated as an individual image whose label is the class of the center pixel in that window. Each labeled window is then used to train a network consisting of a series of convolutional and max pooling layers. Once the network is trained, a sliding window approach, as described in [3], can be used to rapidly classify new images. Some adaptations have been made in order to accommodate the variability in contrast and intensity that is inherent to CT images of composite materials. After classifying the images using a convolutional network, some post-processing techniques remove misclassifications based on other criteria. The final result is an image where most of the nominal composite response has been removed leaving the pixels representing the delamination. Convolutional neural networks have proven to be extremely flexible models that, when given the appropriate training data, are able to simulate a variety of complex machine perception tasks. Such flexibility should allow for detection of other types of defects simply by constructing training sets containing those defects. In the future, the goal is to use the networks as a supplement to a human inspector's analysis.---This work is funded by the Big Data and Machine Intelligence Initiative at NASA Langley Research Center.

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Effect of Fill Conditions on Bulk Wave Scattering from a Through-Hole

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---Angle-beam ultrasonic testing, coupled with wavefield imaging, is an effective means for measuring bulk waves propagating in plate-like structures. In angle-beam testing, bulk waves are incident into a plate at an oblique angle via an angled wedge, and reflect between the surfaces of the plate as they propagate through the medium. A laser Doppler vibrometer system is used to image the resulting wavefield on the surface of the plate in a 2D rectilinear grid. Through-holes are of particular interest because cracks frequently originate at fastener holes in many engineering structures. Boundary conditions inside fastener holes can vary significantly during the life of a structure and thus may affect the results of ultrasonic nondestructive testing methods. In this research, the scattering of bulk waves incident on a through-hole is measured for a variety of fill conditions, such as complete and partial filling with epoxy, plastic and metallic inserts, and grease. Analysis techniques are developed to quantify scattering as a function of angle for different boundary conditions. Experimental results are presented that demonstrate the utility of these techniques for quantifying angle-beam bulk wave scattering from holes.**---**This work is funded by the Air Force Research Laboratory under Contract Number FA8650- 10-D-5210 (Dr. Eric Lindgren, Program Manager).

A study of the dispersion characteristics of leaky surface acoustic waves on a layered thin film structure subjected to the loading and stiffness effect

---**Byung-seok Jo***, Tae-Sung Park*, Jeong-Nyeon Kim**, Bernhard R. Tittmann** and Ik-Keun Park*, *Department of Mechanical and Automotive Engineering, Seoul National University of Science and Technology (Seoultech), Seoul, Korea, **Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA, USA 16802

---In the layered structure, the velocity of leaky surface acoustic wave (LSAW) has a dispersion characteristics and it depends on the material properties of the thin film layer and the substrate[1, 2]. To study these characteristics, two kinds of thin film systems, slow-on-fast structure(loading effect) and fast-on-slow structure(stiffness effect), were used to calculate the corresponding dispersion curves and compared to measurement of the velocity of LSAW with scanning acoustic microscopy(SAM). Ni/Si and Al/Si were used as a slow-on-fast structure and Ti/glass and Si_3N_4/GaAs were used as a fast-on-slow structure. Each of the thin film specimens was variously deposited with different thicknesses using a DC magnetron sputtering and PECVD process by controlling the deposition time. And then, the velocity of LSAW for the each specimen was measured using SAM and the frequency of excitation was 200MHz and 400MHz. In case of the slow-on-fast structure, the velocity of LSAW decreased as the thickness of the thin film increased, but the other case showed two types of results. The velocity of LSAW decreased (Ti/Glass) or increased (Si_3N_4/GaAs) as the thickness of thin film increased. To confirm these results, actual measurement were compared to a theoretical dispersion curves. All results showed a similar trend with corresponding dispersion curves and only the dispersion curve of Ti/Glass had an anomalous behavior. Unlike general fast-on-slow systems, it was fluctuating at the small fd part of the curve. This behavior arises from the combination of material properties (density, sound velocity) between the thin film and the substrate. We confirmed this characteristics by calculated dispersion curves with some combination of material properties.---This work was supported by Radiation Technology R&D program through the National Research Foundation of Korea funded by the Ministry of Science, ICT & Future Planning (NRF-2013M2A2A9043274)

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Electromagnetic Non Destructive Technique for Duplex Stainless Steel Characterization

---João V. G. Rocha, Cesar G. Camerini and Gabriela R. Pereira, Laboratory of Non-Destructive Testing, Corrosion and Welding, Federal University of Rio de Janeiro – RJ, Brazil

---Duplex stainless steel (DSS) is a two phase (ferrite and austenite) material which exhibits an attractive combination of mechanical properties and high corrosion resistance, being commonly employed for equipment of petrochemical plants, refining units and oil & gas platforms. The best properties of DSS are achieved when the phases are in equal proportions. However, exposition to high temperatures (e.g. welding process) may entail undesired consequences, such as deleterious phases precipitation (e.g. sigma, chi) and different proportion of the original phases, impairing dramatically the mechanical and corrosion properties of the material. A detailed study of the magnetic behavior of DSS microstructure with different ferrite austenite ratios and deleterious phases content was accomplished. The nondestructive method evaluates the electromagnetic properties changes in the material and is capable to identify the presence of deleterious phases into DSS microstructure.

Second Harmonic Rayleigh Wave Detection Using a Heterodyne Laser Interferometer

---**Aulon Bajrami**, David Torello, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, Atlanta, GA 30318

---Nonlinear acoustic measurements, including the generation of higher harmonics caused by nonlinear material behavior, have proven to be a useful technique to detect changes in the microstructure of a material, and thus nondestructively characterize material state.
Optical detection of second harmonic Rayleigh waves by means of a heterodyne laser interferometer has advantages over traditional detection techniques such as contact transducers. Laser detection is a non-contact point measurement, which provides absolute readings of the surface displacements and the particle velocity of the Rayleigh surface waves. Frequency or phase Modulation of the laser is caused by the Doppler effect on the velocity and displacement amplitudes of a vibrating specimen. This modulation can be recovered with suitable demodulators. This research explores digital and analog demodulation techniques and their effects on higher harmonic measurements. In addition, this research develops a procedure to reduce spurious effects and to quantify the nonlinearity due to experimental equipment in analog demodulation schemes.

3D Modelling of Air-Coupled Detection of Nonlinear Rayleigh Surface Waves

---**Matthias P. Uhrig**, Jin-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, 1059B Terrell St., NW, Atlanta, GA 30318

---Although several studies have proved the accuracy of using a non-contact, air-coupled receiver in nonlinear ultrasonic (NLU) Rayleigh wave measurements, inconsistent results are obtained from narrow specimens. The objective of this research is to test the hypothesis that reflections from the narrow specimen boundary will distort the signal arriving at the air-coupled receiver surface, and thus cause spurious results in the measured NLU second harmonic generation. The commercial finite element (FEM) package, ABAQUS is used to perform a 3D parametric, numerical investigation of full size models. These numerical FEM models make it possible to consider the effect of different Rayleigh wave propagation paths on the measured NLU signals. The simulation of the fluid-structure interaction leads to a better understanding of the air-coupled measuring technique, and demonstrates the importance of the air-coupled receiver head alignment in relationship to the Rayleigh wave propagation path. The numerical FEM results are validated with analytical and experimental data, show- ing good agreement and underlining the significance of the study performed.

Finite Element Simulation of Higher Harmonic Rayleigh Wave Generation Due to Interaction with Defects

---**Tobias Oberhardt**, Jin-Yeon Kim, Jianmin Qu, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30318

---A Finite Element Model (FEM) is used to investigate the effects of planar defects on initially monochromatic Rayleigh surface waves. The interaction with distributed surface-breaking microcracks, and the generation of higher harmonic Rayleigh surface waves are considered in detail. Rayleigh surface waves are generated using the wedge technique. In order to reduce the influence of reflected waves from the edges and boundaries present in the FEM model, an absorbing environment is created via infinite elements. The asymmetrical stiffness distribution in the cracked region is accounted for by locally assigning a nonlinear stress-strain relationship to small regions of the FEM model. The nonlinear stress-strain relationship serves as a local effective medium that mimicks the opening and closing dynamics of a physical microcrack. The FEM model is used to gain better understanding and insight into nonlinear wave propagation in damaged materials.

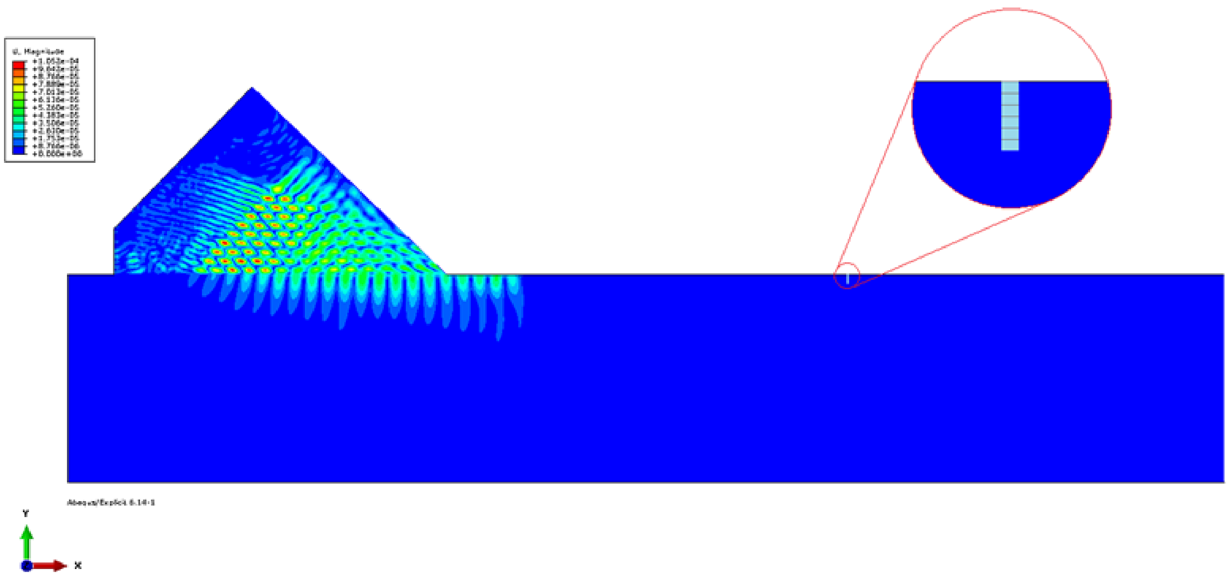

Fig. 1. Displacement magnitude results for plane harmonic waves generated in the wedge-specimen assembly.

Precision Measurement of Crack Closure State with Vibrothermography

---**Bryan Schiefelbein**, Ashraf F. Bastawros, and Stephen D. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50014

There are currently no accurate methods for evaluating closure state along the length of a crack. Here we utilize the fact that closure state is a controlling parameter of vibrothermography testing. Vibrothermographic heating occurs at the closure point where the crack faces are in tenuous contact. By applying multiple external loads and performing vibrothermography tests, we can potentially evaluate the closure state along the length of a crack based on the infrared data obtained and an understanding of the closure mechanics. To accurately evaluate the closure state from the infrared data, we need a method to map the known external load to a crack closure condition. In this poster, we present a simple theory describing the mechanics of partial crack closure, and how the interaction of external and residual stresses alter the point of closure. A model previously suggested by Renshaw [1] assumed the simple addition of the external and residual stress fields to describe the closure state. This approach neglects complicated interactions between the stress fields and the impact of crack geometry. We would like to obtain a more physically consistent representation of the closure state under external loading. This means incorporating the crack geometry, fracture mechanics, and asperity contact. Considering these factors results in a complicated mechanics problem, which we attempt to solve with this simple model. The model outlined by Fleck [2] provides a basis for evaluating the closure point, while weight functions [3] are used to handle complicated stress fields. Asperity contact along the crack faces is modeled using Hertzian theory, which allows us to predict locations along that crack that have left contact, regions that are in high contact (restricting relative motion), and regions that experience interference over a dynamic loading cycle. We have validated the closure state results using a finite element model and have obtained residual stress measurements for experimental cracks by applying the theory to vibrothermography testing results.

Comparison of Ultrasonic Nonlinear Parameters Measured by PZT and $LiNbO_3$ Transducer

---**Jongbeom Kim**[1], Kyoung-Jun Lee[1], Ju-ho Lee[1], and Kyung-Young Jhang[2], [1]Hanyang University, Department of Mechanical Convergence Engineering, Seoul 133-791, Republic of Korea; [2]Hanyang University, School of Mechanical Engineering, Seoul 133-791, Republic of Korea

---The ultrasonic nonlinear techniques have been known as effective methods to evaluate a microstructure change of material. The ultrasonic nonlinear characteristic can be evaluated by the ultrasonic nonlinear parameter β determined from the amplitudes of fundamental and second harmonic frequency components. The ultrasonic nonlinear parameter is generally measured by using a contact transducer; PZT and $LiNbO_3$ transducers are commonly used. However, the measurement result may be dependent on the equipment. Here in, we are curious about whether the nonlinear parameters measured by different transducers are identical. Therefore, in this study, we compare the ultrasonic nonlinear parameters measured by different transducers, PZT and $LiNbO_3$. For the experiment, the Al6061 specimens were heat treated at 220℃ with different aging time 20, 40, 60, 120, 600, 6000, and 60000 min. The ultrasonic nonlinear parameter β measurements were carried out by using two different kinds of transducer, PZT and $LiNbO_3$. The results show that the measured parameter β fluctuates due to the nucleation and growth of precipitates with the aging time and such fluctuation according to the aging time were similar to each other regardless of the type of transducer.---This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (NRF-2013M2A2A9043241). The corresponding author is Kyung-Young Jhang whose email address is kyjhang@hanyang.ac.kr.

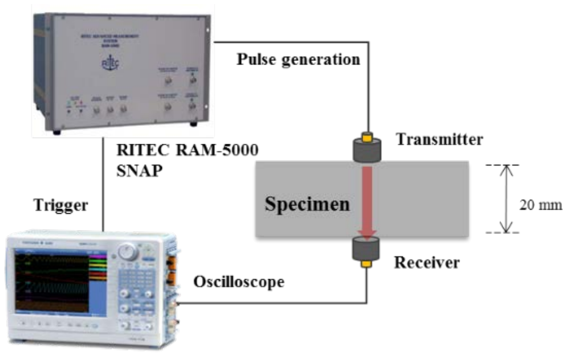

Figure 1. Experimental set up

Volumetric Measurement of Residual Stress Using High Energy X-Ray Diffraction
---**R. Whitesell, A. McKenna**, S. Wendt, and J. Gray, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---We present results and recent developments of laboratory bench-top system using high energy diffraction method, between 50 and 150 KeV, for use in measuring internal strain of moderately sized objects. Traditional x-ray strain measurements are limited to a few microns depths due to the use of Cu k_α or Mo k_α radiation. The use of high energy x-rays for volumetric measurements of strain typically is the domain of synchrotron sources. We discuss the use of industrial 320kVp tube sources to generate brighter x-ray beam along with a method using the intrinsic 40eV width of the k_α characteristic peak of tungsten to measure volumetric strains in a number of industrially relevant materials. We will present volumetric strains measurements from two examples, first, additive manufacturing (AM) parts with various build configurations and, secondly, residual strain depth profiles from shot peened surface treatments. The spatial resolution of these depth profiles is ~50 microns. The development of a faster method as compared to energy dispersive or θ-2θ scans is based on intensity variation measurement of the strain using the afore mentioned 40eV characteristic tungsten k_α line. We have also developed a simulation program for modeling the effect of monochromator slit alignment, detector collimator configurations and several scanning means. We will present recent results on the development of this new tool and on x-ray diffraction measurement at high energy, typically in the range of 60-100 keV.

Ultrasonic Interface Wave Propagation Analysis for the Nuclear Reactor Nozzle Weld

---**Junpil Park**[1], Jaesun Lee[1], Kyung-Young Jhang[2] and Younho Cho[3], [1]Pusan National University, Graduate School, School of Mechanical Engineering, Busan, South Korea, 609-735; [2]Hanyang University, School of Mechanical Engineering, Seoul, South of Korea, 133-791; [3]Pusan National University, BSchool of Mechanical Engineering, usan, South Korea, 609-735

---The nuclear power plant inspection is important for the safety issue. However the nozzle weld is located at inaccessible area such as inside of nuclear reactor, it is difficult to be inspected by conventional ultrasonic testing from the outside of reactor. In this paper, the interface waves propagation model is proposed to analyze the interaction on the shrink fit boundary and weld in nuclear reactor. The nozzle is installed in reactor head with perfect shrink fit condition. Proposed interface waves are propagating along the stainless steel-stainless steel contact boundary which is excited from the outside of reactor head. Theoretical analysis on the displacement distribution on the thickness direction is confirmed by numerical model analysis. Also interface wave propagation model is validated by experimental approach. The numerical and experimental results show good agreement. It is expected that the proposed technique can be a promising solution for nozzle weld online inspection.---This research was supported by INNOPOLOIS Foundation funded by the Ministry of Science, ICT and Future Planning (2014BS001).

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Optimization of X-ray CT data acquisition for the inversion of material characteristics of fibre reinforced composites

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Advanced materials such as fibre-reinforced composites pose a challenge when non-destructively evaluating their physical properties due to their structural complexity. To better understand the defects and anomalies that emerge in components composed of these materials during and after manufacture, a good knowledge of the material itself is necessary. The quality of the NDT data greatly affects the efficiency of any NDT inversion process in generating maps of material properties. The work described in this poster is part of a larger project aimed at the optimization of the inversion techniques used for mapping 3D profiles of fibre reinforced material properties such as porosity, local fibre orientation and fibre volume fraction at a ply level. The NDT data is acquired using X-ray Computed tomography; an excellent candidate for providing full 3D characterization of a structure's internal features, making it a popular validation tool for other measurement modalities, such as ultrasound. Previous work was carried out to test the accuracy and precision of inversion methods such as the Radon transform when determining local fibre orientation in a CT slice[1]. Key to optimizing the inversion techniques is an optimization of the acquisition system to produce the desired 3D X- ray CT data sets. This poster focuses on understanding the different parameters affecting the generation of the X-ray spectrum and the energy distributions of the photons before and after interaction with the specimen, which are all crucial factors. Future work will include further comparative work with ultrasonic inversion methods as well as developments of new X-ray CT inversion algorithms.

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Session 12

SESSION 12
NDE IN THE RAILWAY BRANCH
Michele Caboni and Thomas Heckel, Co-Chairpersons
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3:30 PM **NDT of Railway Components Using Induction Thermography**
---**U. Netzelmann**, G. Walle, A. Ehlen, S. Lugin, M. Finckbohner, and S. Bessert, Fraunhofer Institute for Non-destructive Testing IZFP, University, Campus E3 1, Saarbruecken, Germany

3:50 PM **Non-destuctive Testing and Fracture Mechanics**
---Uwe Zerbst[1], Thomas Heckel[1] and **Michele Carboni**[2], [1]BAM – Federal Institute for Materials Research and Testing, Unter den Eichen 87, D-12205 Berlin, Germany; [2]Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milano, Italy

4:10 PM **Modern NDT Methods for the Detection of Cracks in Shafts and Hollow Axles**
---Hartmut Hintze[1], Arne Rohrschneider[1], Stefan Bethke[1], and **Thomas Heckel**[2], [1]DB Systemtechnik GmbH, Zerstörungsfreie Prüfung und Prüfsysteme, Brandenburg-Kirchmöser, Germany; [2]BAM, Federal Institute for Materials Research and Testing, Berlin, Germany

4:30 PM **A Machine Vision Assisted System for Fluorescent Magnetic Particle Inspection of Railway Wheelsets**
---**Tao Ma**[1], Zhenguo Sun[1], Wenzeng Zhang[1], and Qiang Chen[1,2], [1]Tsinghua University Department of Mechanical Engineering, Beijing, P. R. China, 100084, [2]Yangtze Delta Region Institute of Tsinghua University, Jiaxing, P. R. China, 314006

4:50 PM **Influence of Resonant Transducer Variations on Long Range Guided Wave Monitoring of Rail Track**
---**Philip W. Loveday** and Craig S. Long, CSIR Material Science and Manufacturing, South Africa

5:10 PM **Development of the Electromagnetic Technology for Broken Rail Detection from a Mobile Platform**
---**Y.A. Plotnickov[1],** A. Raghunathan[2], A.K. Kumar[3], J. Noffsinger[4], J.M. Fries[4], S.J. Ehret[3], T. Frangieh[1], and S. Palaganda[2], [1]GE Global Research, Niskayuna, NY, USA; [2]GE Global Research, Bangalore, India, [3]GE Transporation, Erie, PA, USA, [4]GE Transportation, Kansas City, MO USA.

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NDT of Railway Components Using Induction Thermography

---**U. Netzelmann**, G. Walle, A. Ehlen, S. Lugin, M. Finckbohner, and S. Bessert, Fraunhofer Institute for Non-destructive Testing IZFP, University, Campus E3 1, Saarbruecken, Germany

---Induction thermography is an active thermographic technique, where eddy currents are generated in an electrically conducting material. Heat is released due to resistive losses, which can be detected by an infrared camera. At cracks close to the material surface, the induced currents will have to circumvent the crack and areas with increased or decreased current densities are generated. The corresponding thermal contrasts indicate defect locations, show the defect orientation and can provide some information on defect depth. The technique found successful applications for surface crack detection in several industrial branches, with the general aim of searching for alternatives to magnetic particle or liquid penetrant testing. In this contribution, some former developments from IZFP in the field of railway related non-destructive testing will be reviewed. The application of induction thermography in this field is quite new. After discussing the basic principles of this technique, its application to testing of railway wheels after production will be shown. Simulations support the experimental investigations. Another application is testing of rails by inspection from a testing car in movement. A first preliminary experiment was performed on a German railway test site, where natural surface cracks in a rail were successfully detected at train speeds of up to 15 km per hour. Simulations and analytical calculations will be presented that point out the important parameters and limitations of this technique. Advantages of induction thermography in comparison to the established techniques are that a defect image is generated by the camera, giving hints to the defect nature. No close contact of the inductor or the camera to the test object is needed. Defects can be detected in regions where other type of sensors fail due to geometrical restrictions.

3:50 PM

Non-destuctive Testing and Fracture Mechanics

---**Uwe Zerbst**[1], Thomas Heckel[1] and Michele Carboni[2], [1]BAM – Federal Institute for Materials Research and Testing, Unter den Eichen 87, D-12205 Berlin, Germany; [2]Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milano, Italy

---Today, in many industrial applications, non-destructive testing (NDT) and fracture mechanics are individually applied each following its own rules with no much interaction. Non-destructive testing is usually applied within a frame of what might be designated as a "good workmanship" philosophy, i.e., the product is aimed to be as defect-free as possible. Note, however, that "defect-free" does not mean no defects exist, but no defects are larger than some predefined level of acceptability. This kind of quality control is definitely of necessity, but it is rarely based on fitness-for-service arguments and sometimes compromised by real capabilities of NDT. Flaws smaller than specified by such rules are frequently considered as acceptable without any further consideration. Likewise, maintenance NDT inspection intervals during service are specified based on experience, whatever that means, rather than on physical reasoning. Fracture mechanics, on the other hand, is frequently restricted to "crisis intervention" when a defect is detected the existence of which is not permissible following the conventional design rules. One reason for this status is certainly that fracture mechanics has partly the reputation of making things worse in that it releases the strict quality control measures or allows for the existence of cracks. Certainly, this image is the consequence of the applications mentioned above. However, although, principally possible, they are rather the exception than the rule. When, e.g. in a railway axle a crack is found during an inspection, of course, it will be removed. Fracture mechanics, in such a case, has a quite different goal, namely to assist in specifying meaningful inspection intervals such that a potential crack would be found before it grows to its critical size and causes a catastrophic failure. The authors of this paper are confident that the real potential of fracture mechanics is in the design stage, both with respect to quality control as well as for specifying accompanying measures such as inspections during service. For this aim, close cooperation with non-destructive testing is essential and indispensable. The intention of the present paper is to provide a discussion of how non-destructive testing and fracture mechanics can be applied in a complementary manner for ensuring the safe service of components, with special focus on rolling stock materials.

4:10 PM

Modern NDT Methods for the Detection of Cracks in Shafts and Hollow Axles

---**Hartmut Hintze**[1], Arne Rohrschneider[1], Stefan Bethke[1], Thomas Heckel[2], [1]DB Systemtechnik GmbH, Zerstörungsfreie Prüfung und Prüfsysteme, Brandenburg-Kirchmöser, Germany; [2]BAM, Federal Institute for Materials Research and Testing, Berlin, Germany

---For automated non-destructive evaluation of shafts and hollow axles Deutsche Bahn AG operates special ultrasonic inspection systems. This equipment has been designed for the detection of strain induced radial-tangential oriented cracks at an early stage of growth. The non-destructive testing of hollow axles is applied in-service using ultrasonic probes which are inserted in the bore hole. A relevant indication during the inspection will lead to a complete exchange of the wheel set followed by a disassembling of the wheel set for further investigation in the cause of the indication. An approach using phased array techniques in conjunction with the SAFT algorithm (Synthetic Aperture Focusing Technique) has been developed by DB Systemtechnik GmbH, BAM and partners. This approach allows an increase in evaluation performance and thereby the reduction of false-positive calls. This leads to a significant reduction of the number of unnecessary changes of wheel sets. The combination of phased array and SAFT enables depth sizing by evaluation of the crack tip signal due to the increased signal-to-noise ratio. This allows the distinction between cracks and false indications. The UT-SAFT analysis of relevant indications locates the position of the reflection (inside or outside of the axles volumina or close to interface). The possibility of contemporary evaluation of the cause which lead to the relevant indication by this analysis will lead to a significant increase in availability of the rolling stock as well as a reduction of costs caused by omission of additional investigations. When inspecting shafts ultrasonic testing is typically applied on wheel sets dismounted from the boogie. If an in-service inspection would be applicable this would reduce inspection time and cost by a significant amount. This was the origin to build a prototype for the in-service inspection of freight wagons. During the trail test the usability and flexibility of the system has been proofed. Additionally it has been proved that the removal of thin adhesive coatings is not necessary to obtain reliable inspection results. For a long term test phase a reference system has been build up in a work shop where the inspection is focused on wheel set which have been disposed to corrosive environments. DB Systemtechnik GmbH experiences are based on a long lasting development of technologies for inspection of dismounted wheel sets. With adapted probes and devices the results of the tests in the field have been optimized and improved to set up a system for the in-service inspection. An option for a next step is to expand the application on wheel sets with brake discs e.g. for vehicles used for public transport.

4:30 PM

A Machine Vision Assisted System for Fluorescent Magnetic Particle Inspection of Railway Wheelsets

---**Tao Ma**[1], Zhenguo Sun[1], Wenzeng Zhang[1], and Qiang Chen[1,2], [1]Tsinghua University Department of Mechanical Engineering, Beijing, P. R. China, 100084, [2]Yangtze Delta Region Institute of Tsinghua University, Jiaxing, P. R. China, 314006

---A machine vision assisted automatic fluorescent magnetic particle inspection system is proposed for surface defect inspection of railway wheelsets. Fluorescent magnetic particle inspection is a conventional non-destructive evaluation process for detecting surface and slightly subsurface cracks of the wheelsets. Using machine vision instead of workers' direct observation could remarkably improve the working condition and repeatability of the inspection. The system is composed of a semiautomatic fluorescent magnetic particle inspection machine and a vision system. The semiautomatic fluorescent magnetic particle inspection machine is a PLC based machine that carries out the loading, rotation, magnetization, demagnetization and unloading of the wheelsets. The vision system is attached on the machine and consists of ultraviolet LED lamps, GigE Vision cameras, a network switch and an industrial pc. Ten cameras are distributed along the direction of the axis of the wheelset (Fig. 1): two for the axle journals, four for the axle body and four for the wheels. During the inspection step after the magnetization, images of the wheelsets' surface are taken and transmitted to the industrial pc through the network switch. The inspection step is divided into ten phases. In each phase, each camera takes one image of the wheelset and after each phase, the machine rotates the wheelset by 36 degrees to the next orientation. For each wheelset, 100 images are acquired in total. The detection of magnetic particle indications of Quantitative Quality Indicators and cracks is being performed meanwhile. The Quantitative Quality Indicators are standard test shims with artificial defects used to examine the magnetic field distribution on the surface of the wheelsets. The detection of them is achieved by mathematical morphology, Otsu's thresholding and a RANSAC based ellipse fitting algorithm. While in the detection of the cracks, lines are first extracted using mathematical morphology, thresholding and thinning. Then the cracks are recognized by their sizes and a measurement of their curve shapes. After the detection, the cracks' sizes and locations on the surface of the wheelsets are calculated in the real scale.

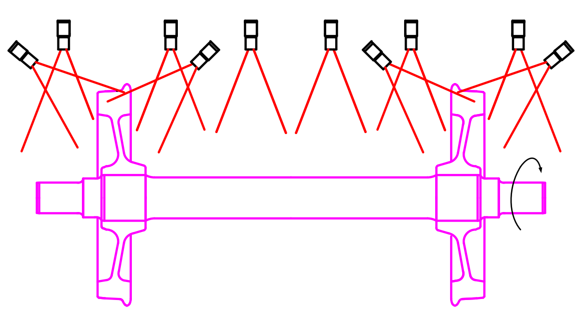

Figure 1. Layout of the cameras.

4:50 PM

Influence of Resonant Transducer Variations on Long Range Guided Wave Monitoring of Rail Track

---**Philip W. Loveday** and Craig S. Long, CSIR Material Science and Manufacturing, South Africa

---The ability of certain guided wave modes to propagate long distances in continuously welded rail track is exploited in permanently installed monitoring systems. Previous work demonstrated that reflections from thermite welds could be measured at distances of the order of 1 km from a transducer array. Numerical modelling has shown that reflections from transverse cracks in the rail head will produce even larger reflections. The availability of numerous thermite welds is useful during the development of a monitoring system as real defects are not available. Measurements of reflections from welds were performed periodically with two permanently installed transducers. Phased array processing was performed and the true location of a weld is indicated by a strong reflection but there is generally also a smaller, spurious replica reflection, at the same distance but in the incorrect direction. An example result is shown in figure 1. In addition, the relative reflection from different welds appears to change over time. The differences between the two transducers and the variation in the transducer characteristics over time are believed to be responsible for the degraded performance. The influence of differences in the amplitude and phase responses of the transducers is investigated. Transducer interaction effects, where a transducer transmits greater amplitude in one direction than the other, have been observed and are investigated. Calibration of the transducers by using reflections from welds is attempted. Simple alternatives to phased array processing are proposed and examined.

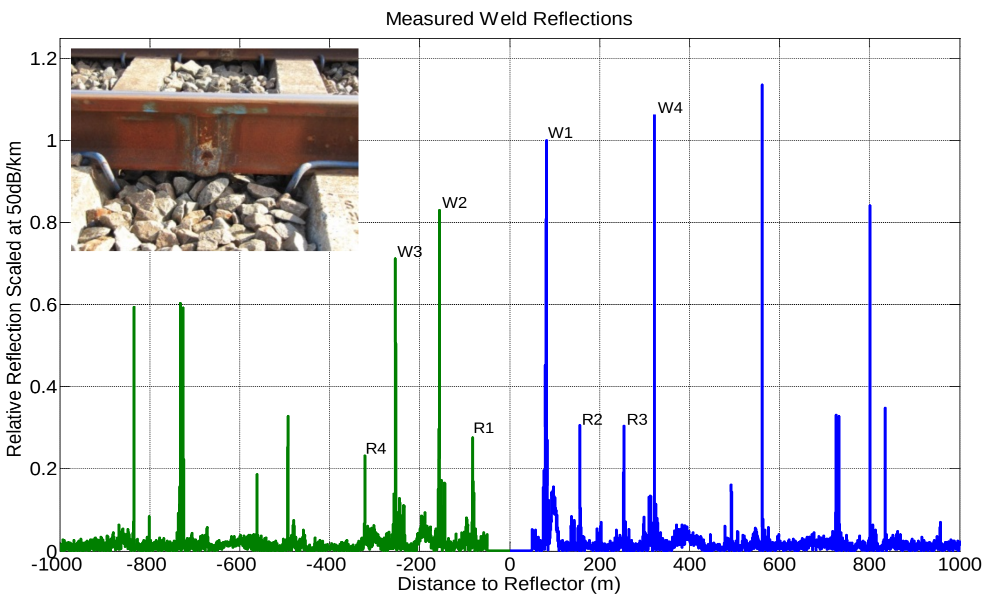

Figure 1. Measured reflections from thermite welds (first four weld reflections labelled ‘W’ and replica reflections labelled ‘R’)

5:10 PM

Development of the Electromagnetic Technology for Broken Rail Detection from a Mobil Platform

by Y.A. Plotnikov,[1] A. Raghunathan[2], A.K. Kumar[3], J. Noffsinger[4], J.M. Fries[4], S.J. Ehret[3], T. Frangieh[1], S. Palanganda[2], [1] GE Global Research, Niskayuna, NY, USA, [2] GE Global Research, Bangalore, India, [3] GE Transportation, Erie, PA, USA, [4] GE Transportation, Kansas City, MO, USA

Timely detection of breaks in running rails remains a topic of significant importance for the railroad industry. GE has been investigating new ideas of the Rail Integrity Monitoring or RIM technology that can be implemented on a wide range of the rolling stock platforms including locomotives, passenger and freight cars. The focus of the project is to establish a simple, non-contact, and inexpensive means of nondestructive inspection by fusion of known solutions with new technology development that can result in detection with high reliability.

A scaled down model of a typical locomotive-track system has been developed at GE Global research for detailed study of the detection process. In addition, a finite element model has been established and used to understand distribution of the magnetic field and currents in such a system. Both models have been using the rails and wheel-axles geometry to establish a realistic model that would provide the electric current and magnetic field distribution close to the real world phenomenon. Initial magnetic field maps were obtained by scanning 1:15 model constructed of steel bars using a 3D scanner and an inductive coil. Sensitivity to a broken rail located between two locomotive axles simulated by an opening in this metallic frame was demonstrated. Further investigation and optimization was conducted on a larger, 1:3 scale, physical model and by running mathematical simulations. Special attention was paid to consistency between the finite element and physical model results. The obtained results allowed establishment of a working frequency range, inductive current injection into the rail-wheel-axle loop and measuring the electromagnetic response to a broken rail.

The verification and full scale system prototype tests are following the laboratory experiments and mathematical simulations.

Keywords: Broken rail, Electromagnetics, Inspection, Finite Element Modeling, Locomotive, Defect detection

Session 13

SESSION 13

MICROWAVE, TERAHERTZ, AND INFRARED NDE

Yuri Plotnikov and Thomas Chiou, Co-Chairpersons
Lakeshore C

3:30 PM **WITHDRAWN - Nondestructive Evaluation of Carbon Fiber Reinforced Plastic (FRP) Defects Using Terahertz Time Domain Spectroscopy (THz—TDS)**
---**Qiang Wang**, X. L. Liao, and X. H. Gu, College of Quality and Safety Engineering, China Jiliang University, Hangzhou, 310018, China

3:50 PM **Microwave Accurate Evaluation of Dielectric Coatings on Carbon Composite Structures**
---R. Zoughi, John Gallion, Matthew Horst, and **Mohammad T. Ghasr,** Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409

4:10 PM **THz Materials Characterization of Mortar Samples with and without Alkali-Silica Reaction (ASR) Gel**
---Ashkan Hashemi, K. M. Donnell, and **R. Zoughi**, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409; Olutosin C. Fawole and Massood Tabib-Azar, University of Utah, Electrical and Computer Engineering Department, Salt Lake City, UT 84112

4:30 PM **Application of Terahertz Technology to Agriculture and Life Sciences**
---**C.-P. Thomas Chiou**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3042

4:50 PM **Evaluation of Uncertainty in Handheld Terahertz Spectroscopy**
---**Josiah Dierken**[2] and Amanda Criner[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, Wright Patterson AFB OH 45433; [2]Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

5:10 PM **NDE of Composite Structures Using Microwave Time Reversal Imaging**
---**Saptarshi Mukherjee**[1], Antonello Tamburrino[1,2], Lalita Udpa[1] and Satish Udpa[1], [1]Nondestructive Evaluation Laboratory, Michigan State University, MI 48824; [2]DAEIMI, UniversitÃ degli Studi di Cassino V. G. Di Biasio, 43 Cassino 03043, Italy

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Nondestructive Evaluation of Carbon Fiber Reinforced Plastic (FRP) Defects Using Terahertz Time Domain Spectroscopy (THz-TDS)

---**Qiang Wang**, X. L. Liao, and X. H. Gu, College of Quality and Safety Engineering, China Jiliang University, Hangzhou, 310018, China

---Composite material is kind of non-metallic materials commonly used in special equipment. The terahertz wave was widely applied in composite material nondestructive field [1,2]. THz radiation penetrates deep into nonpolar and nonmetallic materials such as plastic, fiber, and ceramics that are usually opaque at optical wavelengths. The THz spectrum is able to inspect the delamination, inclusion, mechanical damage etc. in the composite material accurately. Damage to carbon fiber was studied including voids, delaminations, mechanical and heat damage. The T-ray imaging and data of carbon fiber samples with different defects was obtained. The CFPR samples area are all 2*2 cm with 2mm thickness. Experiments of heat damage, voids defect, mechanical damage and flat-hole defect in CFPR were performed. The results show that the heat damage, voids defect, mechanical damage are clearly revealed by reflective THz-TDS imaging (in 0.1-3.5 THz range). And the time domain waveform is sensitive to thermal damage in samples, through local testing to determine the overall performance is especially suitable. In the time domain, the maximum amplitude of the waveform is used to form a 2-D image. The results showed that localized heat damage area is noticeable in the terahertz reflecting TDS image (Fig 1). Darker shade indicates damage spot. ---The work is funded by the National Quality Supervision and Inspection Public Welfare Project of China and Zhejiang Provincial Natural Science Foundation of China (Grant LY14E040002).

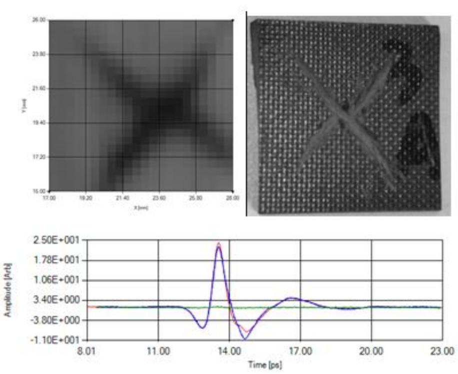

Figure 1. THz-TDS image of CFPR heat damage and THz waveform maximum amplitude of heat damage.

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Microwave Accurate Evaluation of Dielectric Coatings on Carbon Composite Structures

---R. Zoughi, John Gallion, Matthew Horst, and **Mohammad T. Ghasr,** Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409

---The efficacy and utility of microwave thickness and dielectric property evaluation using open-ended rectangular waveguide probes have been studied and perfected during the past two decades. Furthermore, these methods have been recently evolved to give accurate estimation of coating thicknesses in layered structures without any electromagnetic or measurement approximation involved [1-3]. Although the efficacy and potential of these methods has been significantly studied for evaluating dielectric stratified composites and coatings on metal substrates, their applications for evaluating coatings on carbon composite substrates have not been fully investigated (if at all). Carbon composites substrates, particularly when composed of multi-directional carbon fibers, essentially reflect microwave signals similar to a conducting (metallic) substrate. This fact significantly increases the utility of these techniques for evaluating thickness of dielectric coatings such as paint, primer and other coatings (single or multiple layers) applied to such composite substrates. These techniques are noncontact, accurate, fast, and allow for comprehensive evaluation of coating properties (thickness and dielectric properties). Dielectric properties can then be correlated to other materials properties allowing for evaluation of critical characteristics such as cure state, porosity (e.g., microcracking in thermal barrier coatings), etc. This paper gives the fundamental principles on which this technique are based, the recent significant improvements to substantially increase its accuracy, as well as several illustrative results of estimating thickness of dielectric coatings applied to carbon composite substrates. The advantages and limitation of the technique will also be discussed.

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2. M. Fallahpour, H. Kajbaf, M. T. Ghasr, J. T. Case and R. Zoughi, “Simultaneous Evaluation of Multiple Key Material Properties of Complex Stratified Structures with Large Spatial Extent,” *in Review of Progress in Quantitative Nondestructive Evaluation,* eds., D. O. Thompson and D. E. Chimenti, (American Institute of Physics 1430, Melville, NY), **31,** 561-565 (2011).
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THz Materials Characterization of Mortar Samples with and without Alkali-Silica Reaction (ASR) Gel

---Ashkan Hashemi, K.M. Donnell, and **R. Zoughi**, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409; Olutosin C. Fawole and Massood Tabib-Azar, University of Utah, Electrical and Computer Engineering Department, Salt Lake City, UT 84112

---Concrete structures are susceptible to deterioration over time as a results of several different chemical processes that take place such as: chloride permeation leading to corrosion of reinforcing steel bars and alkali-silica reaction (ASR) gel formation when sufficient amounts of water and alkali agents are present. Both of these issues have been significantly and successfully investigated using microwave materials characterization techniques [1-3]. Related to this issue, electromagnetic waves at THz frequencies (greater than1000 GHz) provide the potential for performing molecular spectroscopy owing to the presence of absorption peaks in certain molecules (i.e., CO_2) at these frequencies [4]. Given the much smaller wavelength size at THz frequencies, it may also be possible to generate surface images of a concrete sample indicating the presence of ASR around aggregates and in cracks (similar to a scanning electron microscope (SEM) image). ASR gel formation changes the chemical composition of concrete and it is a signature event that signals the onset of deterioration. Similar to microwave measurement methods, molecular spectroscopy at THz frequencies can be performed in the reflection mode and in a non-contact manner. Here, we use THz spectroscopy to demonstrate the potential possibility of differentiating mortar samples with and without ASR gel content [3]. We will compare the THz measurements results with microwave frequencies to show uniqueness of each and also the potential for combining data from both regimes (data fusion) to obtain a more comprehensive set of information than either alone.

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Application of Terahertz Technology to Agriculture and Life Sciences

---**C.-P. Thomas Chiou**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3042

---In the past decade, electromagnetic radiation in the terahertz frequency range, commonly known as T-ray or THz, has emerged as a powerful sensing modality for material inspection and characterization, and had attracted extensive research efforts across a number of engineering and science disciplines. The existence of distinct spectral “fingerprints” for many substances makes THz particularly useful for material identification and classification. As its capability was explored further in recent years, THz is starting to see increased use in a wide spectrum of applications. In this paper, the application of THz imaging and spectroscopy to the fields of agriculture and life sciences is exploited. We discuss the working principles of “spectroscopic imaging” in reflection and through-transmission modes. We then demonstrate the potential of this technique with selective examples including imaging of live plant leaves, characterization of food additives and classification of wood species.

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Evaluation of Uncertainty in Handheld Terahertz Spectroscopy

---**Josiah Dierken**[2] and Amanda Criner[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, Wright Patterson AFB OH 45433; [2]Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469

---Advances in terahertz spectroscopy have shown it to be an effective tool for the inspection of polymers and ceramics in laboratory environments. Furthermore, recent work has shown promise that terahertz reflectance spectroscopy may be effectively applied to surface characterization of CMCs and PMCs to investigate chemical changes resulting from thermal degradation. However, even under tightly controlled laboratory conditions, various sources of uncertainty such as surface variability, ambient atmospheric conditions, as well as measurement errors within the system will be present. The analysis of measurement uncertainty is further complicated by the fact that reflectance spectra are constituted by the nonlinear relationship between the dielectric spectra and the reflectance spectra, thereby making model calibration more difficult as compared to transmission and absorbance spectroscopy. As inspections transition from laboratory to field-level applications sources of uncertainty must be considered to properly assess the health of a material with any means of statistical significance. In this study, spectra from two terahertz spectroscopy systems are investigated to assess the variation in measurement uncertainty. By characterizing the uncertainty variation, recommendations are proposed for improving inspection procedures in both laboratory and field-level NDE.

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NDE of Composite Structures Using Microwave Time Reversal Imaging

---**Saptarshi Mukherjee**[1], Antonello Tamburrino[1,2], Lalita Udpa[1] and Satish Udpa[1], [1]Nondestructive Evaluation Laboratory, Michigan State University, MI 48824; [2]DAEIMI, UniversitÃ degli Studi di Cassino V. G. Di Biasio, 43 Cassino 03043, Italy

---Composite materials are being increasingly used to replace metals, partially or completely, in aerospace, shipping and automotive industries because of their light weight, corrosion resistance, and mechanical strength. Integrity of these materials may be compromised during manufacturing or due to impact damage during usage, resulting in defects such as porosity, delamination, cracks and disbonds. Microwave NDE techniques have the ability to propagate through composite materials, without suffering much attenuation. The scattered field depends on the dielectric properties of the medium, and hence provides information about the structural integrity of these materials. Time Reversal focusing is based on the fact that when a wave solution is reversed in time and back propagated it refocuses back at the source. This property has been used in ultrasonic NDT [1] to detect defects that act as sources of scattered fields. Recent studies by Fink et. al. [2] has extended this study to wideband electromagnetic waves with promising results. This paper presents a model based parametric study of time reversal principles with microwave data in dielectric and composite materials. A two dimensional FDTD model is developed to implement the forward and time reversed electromagnetic wave propagation in a test geometry comprising metal-composite structures. A Gaussian modulated time pulse at center frequency 2 GHz is radiated and the scattered fields measured at a receiver array are time reversed and retransmitted. The maximum energy of the back propagated field highlights the location of the defect. Simulation results demonstrate the feasibility of this approach to detect and characterize different defects. A parametric study is conducted to understand the effect of defect size; antenna array element configuration will be presented.

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Session 14

SESSION 14
EDDY CURRENT I
Dave Utrata, Chairperson
Nicollet D3

3:30 PM **Eddy Current Circuit Design for Power Maximization of an Omnidirectional Magnetostrictive Patch Transducer**
---**Kiyean Kim**, Hyung Jin Lee, Joo Kyung Lee, and Yoon Young Kim, School of Mechanical and Aerospace Engineering and Institute of Advanced Machinery and Design, Seoul National University, Republic of Korea, South Korea

3:50 PM **Characteristics of Remote Field Eddy Current Testing with Shorter Distance between Surface Type Exciting and Detector Coils**
---**Souichi Ueno**, Noriyasu Kobayashi, and Kawajiri Yuko, Toshiba Corporation, 8 Shinsugita-cho, Isogo-ku, Yokohama 235-8523, Japan

4:10 PM **Rotating Current EC-GMR System for Rapid Scanning of Faster Sites**
---Chaofeng Ye, Zhiyi Su, Michael Saybolt, **Yue Huang**, L. Udpa, and S. S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

4:30 PM **Inspection of Steam Generator Tube Support Structures Using Pulsed Eddy Current**
---**P. R. Underhill**[1], S. G. Mokros[1,2], J. Buck[1,2], J. Morelli[2], and T. W. Krause[1], [1]Royal Military College of Canada, Kingston, Ontario, Canada; [2]Queen's University, Kingston, Ontario, Canada

4:50 PM **Applications and Limitations for Using ACPD in Crack Depth Measurements**
---**D. Utrata** and D. Enyart, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

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Eddy Current Circuit Design for Power Maximization of an Omnidirectional Magnetostrictive Patch Transducer

---**Kiyean Kim**, Hyung Jin Lee, Joo Kyung Lee, and Yoon Young Kim, School of Mechanical and Aerospace Engineering and Institute of Advanced Machinery and Design, Seoul National University, Republic of Korea, South Korea

---This research aims to maximize the power and sensitivity of an omni-directional Lamb wave magnetostrictive patch transducer (OL-MPT) [1] by using an elaborately designed eddy current circuit of an OL-MPT. While most of related earlier works were mainly focused on reducing eddy current loss, this work makes a use of an induced current on a metal plate test specimen on which an OL-MPT is installed. In a traditional OL-MPT, dynamic magnetic field generated from the coil does not penetrate through the thickness of the magnetostrictive patch because the induced current on the surface of the patch tends to cancel out the magnetic field under the patch. So, we propose to slit the circular magnetostrictive patch to change the eddy current path, making magnetic fields applied to a test plate considerably strong beyond the patch. If the test plate is made of metal, eddy current can be induced on the plate, resulting in an increase of net applied dynamic magnetic field inside the patch. Comparing the power increase in the output signals in metal and nonmetal plates, we will show the effectiveness of the proposed slitting method for metal test plates. Both finite element simulations and experiments were performed. We also investigate the effects of the number of slits made in the magnetostrictive patch on the radiation patterns of the modified OL-MPT's.
This research was supported by the National Research Foundation of Korea (NRF) grant (No. 2015-021967 and No. 2014M3A6B3063711) funded by the Korea government (MSIP).

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Characteristics of Remote Field Eddy Current Testing with Shorter Distance between Surface Type Exciting and Detector Coils

---**Souichi Ueno**, Noriyasu Kobayashi, and Kawajiri Yuko, Toshiba Corporation, 8 Shinsugita-cho, Isogo-ku, Yokohama 235-8523, Japan

---Steam generators for fast nuclear reactors compose tubes made ferromagnetic material under liquid sodium. Although, it is need to detect defects outside tubes from inside, for example shallow grooves and small pin holes, in in-service inspection. Sodium coating decreases detectability of these defects. A remote field eddy current testing (RFECT) is potential candidate as its inspection method. We have been developing a RFECT for higher sensitivity. We applied multiple surface coils structure with flux guides to exciting coils and detector coils of a RFECT. This structure makes it possible to shorten the distance between the exciting and detector coils. The exciting and detector coils have the same orientation along the tube axis in the conventional RFECT probe. On the other hand, the exciting and detector coils of new RFECT probe are radially-oriented. As the result, the detector coils are insulated from the influence of the direct field generated by the exciting coils and the distance between the exciting and detector coils is able to be shorter compared to the distance of the conventional RFECT probe. We measured the voltage of a detector coil with varying the distance between exciting and detector coils. This voltage means the intensity of magnetic field inside tubes. The voltage of the new RFECT probe at the distance of 20 mm indicated 10 times value as large as that of the conventional RFECT probe at the distance of 50mm. The defect detection tests were conducted using both new and the conventional RFECT probe. We prepared two specimens. One was a machined whole circumferential groove whose depth is 0.7 mm and width is 10 mm. The other has a pin hole shaped defect, whose the depth is 0.7 mm and the diameter is 1 mm, exposed to sodium coating. We conducted defects detection tests and obtained following conclusion. From results of detection tests of the whole circumferential groove, the conventional RFECT probe could not detect the whole circumferential groove at the distance between the exciting and detector coils of 20 mm, on the other hand, the new RFECT probe at the distance between the exciting and detector coils of 20 mm had about 20 times sensitivity compared to the case of the distance between the exciting and detector coils of 50 mm. From results of detection tests of the pin hole shaped defect with sodium coating, the new RFECT probe at the distance between the exciting and detector coils of 50 mm could detect the pin hole shaped defect clearly. Furthermore, the signals of the pin hole shaped defect were distinguished from the signal of sodium coating by using their phase angles. In conclusion, applying Multi-surface exciting and detector coils make it possible to detect defects at the shorter distance between the exciting and detector coils. Consequently, RFECT probe has high sensitivity for defects.

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Rotating Current EC-GMR System for Rapid Scanning of Faster Sites

---Chaofeng Ye, Zhiyi Su, Michael Saybolt, Yue Huang, L. Udpa, and S. S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

---The detection of subsurface cracks in multi-layer aluminum structures is a challenging problem. Eddy current probes have a major shortcoming due to the skin effect phenomenon where the penetration depth of the field is inversely proportional to the square root of excitation frequency. Although this would suggest the use of lower excitation frequencies to obtain deeper penetration, the drop in signal-to-noise ratio (SNR) observed at lower frequencies presents a major challenge. This drawback can be overcome by using giant magnetoresistive (GMR) sensors to measure the magnetic field directly. GMR sensors offer very high sensitivity over a wide range of frequencies, from dc to megahertz (MHz). In conventional EC-GMR systems, the induced currents are primarily generated along a single direction in the test sample making it more sensitive to cracks perpendicular to EC flow. However, when a crack is parallel to the EC flow, the ability to detect defects decreases significantly. In order to ensure the EC system is capable of detecting defects independent of their orientation, an excitation method using orthogonal coils was proposed for generating a rotating planar excitation current with uniform sensitivity to cracks of all orientation. For rapid inspection of a row of rivets, we use a linear array of GMR sensors so that the rivet area can be imaged in a single scan. The main challenges of applying array sensors to rotating field coil design are as follows: (1) the use of a linear array results in a large background field measured by the sensors that are not on the center of two orthogonal coils; (2) Non-uniformity of field in sensor region which leads to non-uniform eddy current in the tested sample; (3) a lot of wires required to connect the array sensors if using full bridge circuit. This paper presents a technique for eliminating the background field using differential measurements[1] and a simplified array sensors application circuit. Initial experimental results show the feasibility of the approach. Experimental results obtained using the system to inspect a riveted two-layer aluminum sample with different size cracks will be presented in the full paper.**---**This material is based upon work supported by the AFRL under Contract FA8650-10-D-5806-5210, Task Order 028. We acknowledge the benefit of extensive technical discussions with Charles Buynak, Eric Lindgren and Gary Steffes in the planning and execution of this effort. We sincerely appreciate their assistance and support.

Reference:

1. Chaofeng Ye, Yue Huang, L.Udpa, and S.S. UDPA, “Rotating Current EC -GMR Probe with Differential Measurement for Inspecting Multilayer Riveted Structures,” *Sens. J. IEEE*.

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Inspection of Steam Generator Tube Support Structures Using Pulsed Eddy Current

---P. R. Underhill[1], S. G. Mokros[1,2], J. Buck[1,2], J. Morelli[2], and **T. W. Krause**[1], [1]Royal Military College of Canada, Kingston, Ontario, Canada; [2]Queen's University, Kingston, Ontario, Canada

---Degradation and fouling of support structures in nuclear steam generators can result in damage to steam generator (SG) tubes and loss of SG efficiency. Conventional eddy current technology, as applied from within tubes, is extensively used to detect tube defects at ferromagnetic supports, but has limited capabilities when 1) multiple degradation modes and fouling are present or 2) evaluation of more remote support structure condition is required. Pulsed eddy current (PEC) technology has been developed for the inspection of support structure degradation. Recent work has demonstrated capability of PEC to simultaneously measure SG tube off-centering and increase in hole diameter, which simulates the presence of support structure corrosion. This presentation further examines the changes to PEC signals when SG tube frets are present. In addition, adaptation of probe design for inspection of trefoil broach supports, demonstrates capability to detect far side ligament wall loss due to flow assisted corrosion, even in the presence of magnetite fouling. Finite element method modeling of PEC probe response to wall loss and magnetite fouling in broach supports helps elucidate measured transient electromagnetic processes.

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Applications and Limitations for Using ACPD in Crack Depth Measurements

---**D. Utrata** and D. Enyart, Iowa State University, Center for Nondestructive Evaluation,
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----The potential drop method may be used for measure crack depth in metallic specimens. This paper presents guidelines for the use of alternating current potential drop (ACPD), using a commercially available device, to measure crack depths. Samples of varying conductivity and geometry have been investigated to define the anticipated limits of accurate crack depth measurement in different materials and components. This was done primarily using machined notches to simulate cracks. Measurements of real cracks have also been made and their profiles predicted prior to breaking open. Effects of some types of crack propagation on accurate measurements were observed. Additionally, various surface preparation techniques have been examined, and their efficacy discussed. The perspective was to generate cautionary restrictions as warranted for various manufacturing users.

Session 15

SESSION 15
6th EAW
Lakeshore A

APPLICATIONS IN INDUSTRY
Martin Spies and Lloyd Schaefer, Co-Chairpersons

1:30 PM **Overview of the Program to Assess the Reliability of Emerging Nondestructive Techniques Open Testing and Study of Flaw Type Effect on NDE Response**
---**Ryan M. Meyer**, Susan Crawford, and Michael T. Anderson, Pacific Northwest National Laboratory, Rihland, WA 99352; Tommy Zetterwall, Swedish Qualification Center, Täby, Sweden; Ichiro Komura, Japan Power Engineering and Inspection Corporation, Yokohama, Japan; Kyung-cho Kim, Korea Institute of Nuclear Safety, Daejeon, South Korea; Iouri Prokofiev and Stephen C. Cumblidge, Nuclear Regulatory Commission, Washington D.C.

2:10 PM **Integration of Reliability Studies in the Development of NDT for the Swedish Spent Nuclear Fuel Disposal Canister**
---**Ulf Ronneteg**[1], Marija Bertovic[2], Mato Pavlovic[2], and Thomas Grybäck[1]; [1]SKB, Swedish Nuclear Fuel and Waste Management Co., Oskarshamn, Sweden; [2]DGZfP Ausbildung und Training GmbH

2:30 PM **Influence on the POD by the Scanning Raster**
---**Thomas Heckel**, BAM Bundesanstalt fur Materialforschung und -prufung, FG 8.4, Berlin 12205, Germany; Johannes Vrana, Marcel Preiβel, DGZfP

2:50 PM **POD Curves for Non-Maximizable Ultrasonic Responses: Statistical Derivation and Application to Solid Freight Axles**
---**M. Carboni**[1] and S. Cantini[2], [1]Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milano; [2]Lucchini RS SpA, Via G. Paglia 45, 24065 Lovere (BG)

3:10 PM ***Break***

APPLICATIONS IN INDUSTRY
Stephen Cumblidge and Daniel Kanzler, Co-Chairpersons

3:30 PM **Optimization of Sensitivity Overheads for Pipe End Inspection via POD-Analysis**
---Thomas Orth and Till Schmitte, Salzgitter-Mannesmann Forschung GmbH, Ehingerstrasse 200, 47259 Duisburg, Germany; **Martin Spies**, Fraunhofer-Institut for Nondestruction Testing IZFP, Campus E3 1, 66123 Saarbrücken, Germany; Thomas Kersting, Europipe GmbH – Werk Mülheim, Wiesenstraße 36, 35473 Mülheim an der Ruhr, Germany

3:50 PM **Measuring the Reliability of Magnetic Particle Inspections as Applied to the API and ASME Codes for Use on Aging Infrastructure**
---**L. Schaefer**, Sr. Advising Engineer, Pacific Gas & Electric Company, Applied Technology Services, 2400 Crow Canyon Road, San Ramon, CA 94583

4:10 PM **Assessment of ASTM Adopted and Proposed Hit/Miss and A-hat vs. a Documents against Handbook/guideline 1823 Recommendations**
---**L. Schaefer**, Sr. Advising Engineer, Pacific Gas & Electric Company, Applied Technology Services, 2400 Crow Canyon Road, San Ramon, CA 94583

4:50 PM **Assessment of Reliability of Remote Visual Testing**
---**Pradeep Ramuhalli**[1], Jeffrey Landrum[2], Michael Anderson[1], Chris Joffe[2], John Lindberg[2], Matt Prowant[1], Mike Larche[1], Traci Moran[1], [1]Pacific Northwest National Laboratory, Richland, WA 99352; [2]Electric Power Research Institute, Charlotte, NC 28262

5:10 PM **Partial Coverage Inspection Using Extreme Value Theory on Ultrasonic C-scan Data**
---**Daniel Benstock** and Frederic Cegla, Imperial College London, NDE Group, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

1:30 PM

Overview of the Program to Assess the Reliability of Emerging Nondestructive Techniques Open Testing and Study of Flaw Type Effect on NDE Response

---**Ryan M. Meyer**, Susan Crawford and Michael T. Anderson, Pacific Northwest National Laboratory, Richland, WA 99352; Tommy Zetterwall, Swedish Qualification Center, Täby, Sweden; Ichiro Komura, Japan Power Engineering and Inspection Corporation, Yokohama, Japan; Kyung-cho Kim, Korea Institute of Nuclear Safety, Daejeon, South Korea; Iouri Prokofiev and Stephen C. Cumblidge, Nuclear Regulatory Commission, Washington D.C.

---In February 2012, the U.S. Nuclear Regulatory Commission (NRC) executed agreements with VTT Technical Research Centre of Finland, Nuclear Regulatory Authority of Japan (NRA, former JNES), Korea Institute of Nuclear Safety (KINS), Swedish Radiation Safety Authority (SSM), and Swiss Federal Nuclear Safety Inspectorate (ENSI) to establish the Program to Assess the Reliability of Emerging Nondestructive Techniques (PARENT) to conduct a series of round-robin tests on large-bore dissimilar metal welds (LBDMW), small-bore dissimilar metal welds (SBDMW), and bottom-mounted instrumentation (BMI) penetration welds. The goal of PARENT is to investigate the effectiveness of current emerging and perspective novel nondestructive examination procedures and techniques to find flaws in nickel-alloy welds and base materials. This is done by conducting a series of open and blind international round-robin tests on a set of LBDMW, SBDMW, and BMI test blocks. The purpose of blind testing was to study the reliability of more established techniques and included only qualified teams and procedures. The purpose of open testing is aimed at a more basic capability assessment of emerging and novel technologies. The range of techniques applied in open testing varied with respect to maturity and performance uncertainty and were applied to a variety of simulated flaws. This paper will include a brief overview of the PARENT open testing and present some of the open testing results. This discussion will be supplemented with additional data from participant countries regarding NDE responses from simulated flaw types drawing some correlations between features in the NDE responses with the flaw type. This information is important to gaining an improved understanding how the NDE responses from simulated flaws in laboratory studies relate to NDE responses in the field. Further, such insight may be incorporated into improve flaw simulation methods for future NDE reliability studies.

2:10 PM

Integration of Reliability Studies in the Development of NDT for the Swedish Spent Nuclear Fuel Disposal Canister

---**Ulf Ronneteg**[1], Marija Bertovic[2], Mato Pavlovic[2], and Thomas Grybäck[1]; [1]SKB, Swedish Nuclear Fuel and Waste Management Co; Oskarshamn, Sweden; [2]DGZfP Ausbildung und Training GmbH

---In the KBS-3 system the Swedish spent nuclear fuel is encapsulated in canisters consisting of a cast iron insert surrounded by a 5 centimetre thick shell of copper. The canisters are disposed in crystalline bedrock at a depth of about 500 meters surrounded by bentonite clay. To verify that the canisters fulfil the requirements, an extensive programme for quality control is developed. In this programme the use of non-destructive testing (NDT) is vital and therefore it is very important to develop reliable NDT methods. Commonly, the reliability of NDT in the nuclear field is only analysed on a technical basis, and only in the stage of the technical justification of the methods. Early in the development of mechanised ultrasonic inspection techniques for inspection of the canister, the reliability of preliminary inspection techniques was analysed using conventional POD-curves (Probability of Detection). The results showed that the techniques were promising but that further optimisation was needed. This raised the question: is it possible to further integrate reliability analyses in the NDT development, and if so, how can this be done? This led us to, with the use of sophisticated POD-models, analyse the detection capabilities and thereby identify the weak spots and the needs for further improvement. Additionally, the reliability analyses also focused on the human factors in the application of mechanised inspection techniques, especially in the field of evaluation of collected data. Aided by the eye tracking methodology, the written instructions and their use during the data evaluation were experimentally investigated. The results then served as a basis for optimisation of the instructions and definition of needs for specific operator training. Furthermore, in order to identify weak spots in both data acquisition and data evaluation customised Failure Mode and Effect Analyses (FMEA) were applied in several steps.

2:30 PM

Influence on the POD by the scanning raster

---**Thomas Heckel,** BAM Bundesanstalt fur Materialforschung und -prufung, FG 8.4, Berlin 12205, Germany; Johannes Vrana, Marcel Preiβel, DGZfP

---Quality standards for heavy rotor forgings in the field of energy production e.g. turbines and generators are constantly rising. This is the reason for the ongoing automatization process of NDT methods during production. Volumetric inspection of these components is carried out by automated ultrasonic inspection. The scanning grid is defined by the resolution of the scanning axis (distance between adjacent measurement points) and the displacement between scanning tracks (distance between adjacent scanning tracks). The mentioned forgings feature a fine grained microstructure due to the manufacturing process and the heat treatment. From an ultrasonic point of view this leads to low attenuation coefficients and care has to be taken that phantom echoes will not occur during scanning. To avoid phantom echoes the pulse repetition rate needs to be lowered which increases inspection time. Optimization of the scanning grid and the pulse repetition rate means optimization of inspection time and inspection costs. The current standards recommend different instructions for the definition of the scanning grid, which are partially ambiguous or not applicable for automated inspection. This has been the motivation for DGZfP subcommittee “UT Automated Inspection Systems” to work on a guideline for the procedure of defining an optimal scanning grid of forgings taking the sound field parameters of the probes used into account.

This contribution discusses the guidelines approach for defining the optimal scanning grid by the means of simulation results and experimental tests. The influence of the scanning grid on the probability of detection (POD) has been evaluated. On this POD calculations have been carried out where the dependency between the detectable size of a flaw and the test grid has been investigated in. The results of the simulation have been verified using test blocks.

2:50 PM

POD Curves for Non-Maximizable Ultrasonic Responses: Statistical Derivation and Application to Solid Freight Axles

---**M. Carboni**[1] and S. Cantini[2], [1]Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milano; [2]Lucchini RS SpA, Via G. Paglia 45, 24065 Lovere (BG)

---The most relevant standards on ultrasonic testing, and an effective inspection practice, require the maximization of echo responses due to indications, before their evaluation in terms of amplitude and size. This is achieved effectively pointing the acoustic axis of the sound beam to the reflecting area of the indication, in a way to get back the maximum possible sound energy. Considering some operative cases, however, such a response maximization is not always feasible, mainly due to geometrical constraints impeding the inspection of the whole control area with a constant sensitivity. The traditional end inspection of solid railway axles by a rotating probe mounting conventional sensors falls back into this kind of inspections. In particular, inspection angles are fixed and the probe holder cannot move along the axle allowing response maximization of in-service damages located, for example, along the body. It follows some control areas cannot be inspected using the maximum sound pressure. The present research shows how the derivation of POD curves for non-maximizable ultrasonic responses cannot be carried out by the traditional statistical approach and a novel one, of the MAPOD kind, is consequently proposed based on experiments and numerical simulations.

3:30 PM

Optimization of Sensitivity Overheads for Pipe End Inspection via POD-Analysis

---Thomas Orth and Till Schmitte, Salzgitter-Mannesmann Forschung GmbH, Ehingerstrasse 200, 47259 Duisburg, Germany; **Martin Spies**, Fraunhofer-Institut for Nondestructive Testing IZFP, Campus E3 1, 66123 Saarbrücken, Germany; Thomas Kersting, Europipe GmbH – Werk Mülheim, Wiesenstraße 36, 45473 Mülheim an der Ruhr, Germany

---The application of new inspection techniques to increase the inspection speed in the area of industrial production requires the evaluation of their performance in view of the tolerable and thus detectable defect types and defect sizes. In a recent POD-study we have shown, that phased-array techniques in comparison with conventional inspection techniques allow for a more sensitive detection, which ranges from 0.5 mm to 1 mm depending on the depth of the considered disk-shaped reflectors [European Conference on NDT ECNDT 2014, Prague, Czech Republic]. Here, a clear-cut correlation between the decision threshold values, the Probability of Detection POD and the Probability of False Indication PFI exists, which represents an important aspect for the practical implementation. In this contribution we report on results, which we have obtained in the course of model-based, virtual as well as experimental investigations of this correlation. In a first step, we have applied calculation procedures implemented at Fraunhofer Institute in order to illustrate the interplay of calibration (referring to 3 mm or 5 mm flat-bottom hole), sensitivity overhead, decision threshold and data scatter. These ‚â versus a' POD-analyses provide a quantitative evaluation and allow for the optimized setting of sensitivity overheads. We have then experimentally investigated the model-based results with respect to pipe end inspection using a ferritic steel test pipe with artificial defects of different dimensions. We present the obtained results and discuss their significance for inspection procedures in industrial production environments.

3:50 PM

Measuring the Reliability of Magnetic Particle Inspections as Applied to the API and ASME Codes for Use on Aging Infrastructure

---**L. Schaefer**, Sr. Advising Engineer, Pacific Gas & Electric Company, Applied Technology Services, 2400 Crow Canyon Road, San Ramon, CA 94583

---Considerable parametric studies and understanding have been developed towards answering the question “How well is our NDE working”, for the Penetrant Inspection method. Magnetic Particle inspection, at its end-point relies on many of the same signal to noise characteristics; indication brightness and contrast with its surroundings. The electromagnetic properties of the material under test and interactions with the applied field and indicating particles used add however considerable dimensions to the response matrix. This paper will present some of the early Probability of Detection experiments conducted in lab/field environments using common MT parameters, and the data will be presented using the rigor of guideline/handbook 1823 using the R code generated by C Annis at Statistical Engineering.

4:10 PM

Assessment of ASTM adopted and proposed Hit/Miss and A-hat vs. A documents against handbook/guideline 1823 recommendations

---**L. Schaefer**, Sr. Advising Engineer, Pacific Gas & Electric Company, Applied Technology Services, 2400 Crow Canyon Road, San Ramon, CA 94583

---From the early Al Behrens probability of detection assessment documentation and software from the Wright Patterson lab, to the most recent material expansion in handbook 1823 from Charles Annis et al, we have seen an appropriate trend to further increase the level of rigor and documentation, especially regarding flaw detection experimental rigor, documentation and statistical rigor in generating the familiar probability of detection and confidence curves. Why is it appropriate? In order for the customers of such data to make effective decisions in design, lifing, or understanding the reliability of a proposed NDE sensor or system, we must minimize the variability in NDE reliability assessments. While there may be an early, or intermediate/ROM results motivation for brevity in the approach to an assessment, use of such tools, as proposed in recent published and proposed ASTM documents must be appreciated in the context of the non-trivial risk attendant. This paper presents a gap analysis between 1823 methods and the ASTM proposed hit/miss and a-hat vs a procedures.

4:50 PM

Assessment of Reliability of Remote Visual Testing

---**Pradeep Ramuhalli**[1], Jeffrey Landrum[2], Michael Anderson[1], Chris Joffe[2], John Lindberg[2], Matt Prowant[1], Mike Larche[1], Traci Moran[1], [1]Pacific Northwest National Laboratory, Richland, WA; [2]Electric Power Research Institute, Charlotte, NC

---Visual testing (VT) is commonly used for the inspection of some components in nuclear power plants. Remote VT with radiation-hardened submersible closed-circuit video systems has been used by nuclear utilities to find degradation in both pressurized and boiling water reactor internals, and to investigate leaks in piping and other components. There is wide variation in the procedures applied to conducting visual examinations, as well as in the equipment used and personnel skill levels. The range of potential variability requires that the capabilities and limitations of remote VT in determining the structural integrity of reactor components be assessed. PNNL[1] and the Electric Power Research Institute[2] are cooperating to conduct a series of round-robin studies to assess the reliability of remote VT procedures and equipment, and to identify variables significantly impacting reliability. A number of variables (such as crack length and opening, procedure variability, etc.) were assessed using a blind testing protocol. Analysis of the results from this study provided a quantitative assessment of the reliability of remote VT procedures, within the constraints of this study, and provided specific recommendations for improving the overall reliability. These recommendations will be tested in a follow-on study being conducted in Fall 2015/Spring 2016. An overview of the studies and a summary of the outcomes will be discussed in this paper.---[1]The work was sponsored by the U.S. Nuclear Regulatory Commission under U.S. Department of Energy Contract DE-AC05-76RL01830; NRC JCN V6323; Mr. Wallace Norris, Program Monitor. [2]The work was sponsored by EPRI member utilities.

5:10 PM

Partial Coverage Inspection Using Extreme Value Theory on Ultrasonic C-scan Data

---**Daniel Benstock** and Frederic Cegla, Imperial College London, NDE Group, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Ultrasonic thickness C-scans provide information about wall thickness of a component over the entire inspected area. They are performed to determine the condition of a component. However, this is time consuming, expensive and can be unfeasible where access to a component is restricted. The pressure to maximise inspection resources and minimise inspection costs has led to both the development of new sensing technologies and inspection strategies. Partial coverage inspection aims to tackle this challenge by using data from an ultrasonic thickness C-scan of a small fraction of a component's area to extrapolate to the condition of the entire component. Extreme value analysis is a particular tool used in partial coverage inspection. Typical implementations of extreme value analysis partition a thickness map into a number of equally sized blocks and extract the minimum thickness from each block. Extreme value theory provides a limiting form for the probability distribution of this set of minimum thicknesses, from which the parameters of the limiting distribution can be extracted. This distribution provides a statistical model for the minimum thickness in a given area, which can be used for extrapolation. In this presentation the basics of extreme value analysis and its assumptions are introduced. We discuss a new method for partitioning a thickness map, based on ensuring that there is evidence that the assumptions of extreme value theory are met by the inspection data. Examples of the implementation of this method are presented on both simulated and experimental data. Further it is shown that realistic predictions can be made from the statistical models developed using this methodology.

Session 16

SESSION 16
COMPOSITES I
Michael Lowe and Dan Barnard, Chairpersons
Nicollet D2

3:30 PM **Improved FE Simulation of Ultrasound in Plastics**
---**J. S. Egerton**[1], M. J. S. Lowe[1], and P. Huthwaite[1], [1]Imperial College London, Exhibition Road, London SW7 2AZ, United Kingdom; H. V. Halai[2], [2]EDF Energy Nuclear Generation Ltd., London SW7 2AZ, United Kingdom

3:50 PM **High Contrast Ultrasonic Imaging of Resin-Rich Regions in Graphite/Epoxy Composites Using Entropy**
---**Michael S. Hughes**[1], John E. McCarthy[2], Jon N. Marsh[2], and Samuel A. Wickline[2], [1]Pacific Northwest National Laboratory, Richland, WA 99354; [2] Washington University in Saint Louis, Saint Louis, MO, 63130

4:10 PM **A 2-D Areal Scan for Imaging Composite Damage Using an Enhanced CCRTM Technique**
---**Jiaz He**[1,2], Fuh-Gwo Yuan[1,2], [1]Center for Integrated Structural Health Management, National Institute of Aerospace, Hampton, VA 23666; [2]Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695

4:30 PM **The Effects of Experimental Configuration on the Efficacy of Coda Wave Interferometry for the Measurement of Thermally Induced Ultrasonic Velocity Variations in CFRP Laminates**
---**Richard Livings**[1,2], Vinay Dayal[1,2], and Dan Barnard[2], [1]Department of Aerospace Engineering and [2]Center for Nondestructive Evaluation, Iowa State University, Ames IA 50011

4:50 PM **Novel Self-Sensing Carbon Nanotube-Based Composites for Rehabilitation of Structural Steel Members**
---**Shafique Ahmed**[1,4], Sagar Doshi[2,4], Thomas Schumacher[1,4], Erik T. Thostenson[2,3,4], Jennifer McConnell[1,4], [1]Department of Civil and Environmental Engineering; [2]Department of Mechanical Engineering; [3]Department of Materials Science Engineering; [4]Center for Composite Materials University of Delaware; Newark, Delaware 19716

3:30 PM

Improved FE Simulation of Ultrasound in Plastics

---**J. S. Egerton**[1], M. J. S. Lowe[1], and P. Huthwaite[1], [1]Imperial College London, Exhibition Road, London SW7 2AZ, United Kingdom; H. V. Halai[2], [2]EDF Energy Nuclear Generation Ltd., London SW7 2AZ, United Kingdom

---Accurate finite-element modelling of ultrasound in high-density polyethylene (HDPE) must account for frequency-dependent behaviour, but frequency domain modelling is prohibitively expensive for all but the smallest models. Here we present a *multiband time domain* simulation technique to address this via application to nuclear power station cooling water pipe systems. HDPE offers improved performance over existing pipe materials, such as cast iron, by not corroding internally or externally. The nuclear power industry has begun ongoing installation of HDPE as a replacement material, but occasional defects form in HDPE pipe fusion joints at the production stage. This necessitates suitable volumetric NDE to safely and reliably assess joint integrity. Ultrasonic NDE is the most viable current technique, but improved inspection capability is needed. The proposed *multiband* technique is a computationally efficient and accurate approach to time domain FE modelling of ultrasonic wave propagation. It could be used to validate the NDE of a large range of candidate weld defects in HDPE. The proposed model uses a small number of time domain FE simulations at individual frequency bands that together cover the bandwidth of interest. The frequency dependence of acoustic properties of ultrasound in HDPE is accurately represented and the model could be straightforwardly generalised to other media.

3:50 PM

High Contrast Ultrasonic Imaging of Resin-Rich Regions in Graphite/Epoxy Composites Using Entropy

---**Michael S. Hughes**[1], John E. McCarthy[2], Jon N. Marsh[2], and Samuel A. Wickline[2], [1]Pacific Northwest National Laboratory, Richland, WA 99354; [2] Washington University in Saint Louis, Saint Louis, MO, 63130

---This study compares different approaches for imaging a near-surface resin-rich defect in a thin graphite/epoxy plate using backscattered ultrasound. The specimen was created by cutting a circular hole in the second ply; this region filled with excess resin from the graphite/epoxy sheets during the curing process. Backscattered waveforms were acquired using a 4 in. focal length, 5MHz center frequency broadband transducer, scanned on a 100x100 grid of points that were 0.03x0.03 in. apart. The specimen was scanned with the defect side closest to the transducer. Consequently, the reflection from the resin-rich region cannot be gated from the large front-wall echo. At each point in the grid 256 waveforms were averaged together and subsequently used to produce peak-to-peak, Signal Energy (sum of squared digitized waveform values), as well as entropy images of two different types (a Renyi entropy $I_{f,\infty}$, and a joint entropy $H_{f,g}$). As the figure shows, all of the entropy images exhibit better border delineation and defect contrast than the either peak-to-peak or Signal Energy. The best results are obtained using the joint entropy of the backscattered waveforms with a reference function. Two different references are examined. The first is a reflection of the insonifying pulse from a stainless steel reflector. The second is an approximate optimum obtained from an iterative parametric search. The joint entropy images produced using this reference exhibit three times the contrast obtained in previous studies.

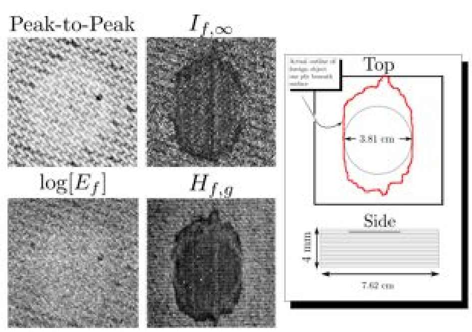


Figure 1. Left: conventional images of defect, middle column entropy images, right defect diagram. All images were prepared from the same raw data.

References:

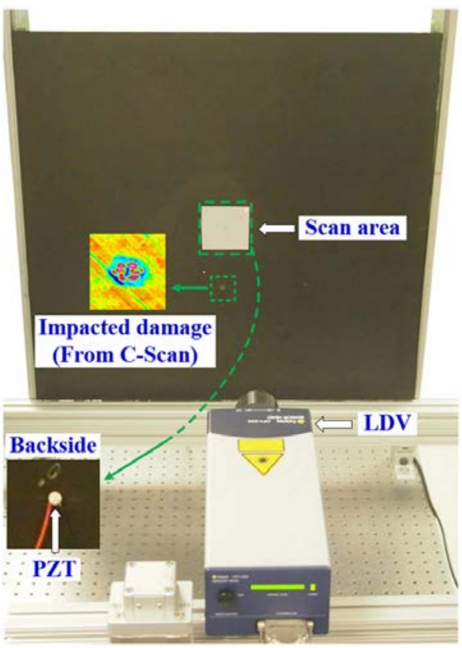
1. M. S. Hughes, J. E. McCarthy, M. Wickerhauser, J. N.Marsh, J. M. Arbeit, R. W. Fuhrhop, K. D. Wallace,T. Thomas, J. Smith, K. Agyem, G. M. Lanza, and S. A.Wickline, Real-time calculation of a limiting form of the Renyi entropy applied to detection of subtle changes in scattering architecture," *J. Acoust. Soc. Am.*, vol. 126, no. 6, pp. 2350-2358, 2009.
2. M. Hughes, J. McCarthy, J. Marsh, and S. Wickline, "Entropic vs. energy waveform processing: A comparison based on the heat equation," in *Proceedings of the Fall 2014 Acoustical Society Meeting*, 2014.

4:10 PM

A 2-D Areal Scan for Imaging Composite Damage Using an Enhanced CCRTM Technique

---**Jiaze He**[1,2], Fuh-Gwo Yuan[1,2], [1]Center for Integrated Structural Health Management, National Institute of Aerospace, Hampton, VA 23666; [2]Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695

---This poster presents a two-dimensional (2-D) non-contact areal scan system to image and quantify impacted damage in a composite plate using an enhanced zero-lag cross-correlation reverse-time migration (E-CCRTM) technique. The system comprises a single piezoelectric actuator mounted onto the composite plate and a laser Doppler vibrometer (LDV) for scanning a region for capturing the scattered wavefield in the vicinity of the PZT. The proposed damage imaging technique takes into account the amplitude, phase, geometric spreading, and all the frequency content of the Lamb waves propagating in the plate, thus, the reflectivity coefficients of the delamination can be calculated and potentially be related to damage severity. Comparisons are made in terms of damage imaging quality between 2-D areal scans and linear scans as well as between the proposed and existing imaging conditions. The experimental results show that the 2-D E-CCRTM has robust performance to image and quantify impacted damage in large-scale composites using a single PZT actuator with a nearby areal scan using LDV.



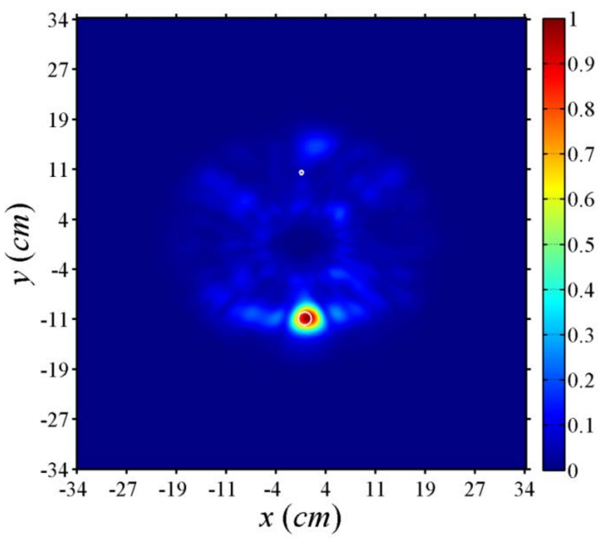


Figure 1. Hybrid PZT/LDV scanning system. Figure 2. Damage imaging using 2D E-CCRTM.

4:30 PM

The Effects of Experimental Configuration on the Efficacy of Coda Wave Interferometry for the Measurement of Thermally Induced Ultrasonic Velocity Variations in CFRP Laminates

---**Richard Livings**[1,2], Viany Dayal[1,2], and Dan Barnard[2], [1]Department of Aerospace Engineering and [2]Center for Nondestructive Evaluation, Iowa State University, Ames IA 50011

---Ultrasonic velocity measurement is a well-established method to measure properties and estimate strength as well as detect and locate damage. Determination of accurate and repeatable ultrasonic wave velocities can be difficult due to the influence of environmental and experimental factors. Diffuse fields created by a multiple scattering environment have been shown to be sensitive to homogeneous stresses such temperature variations, and Coda Wave Interferometry has been used to measure the thermally induced ultrasonic velocity variation in concrete, aluminum, and the Earth's crust [1, 2, & 3]. In this work, we analyzed the influence of several parameters of the experimental configuration on the sensitivity and resolution of the measurement of thermally induced ultrasonic velocity variations in a carbon-fiber reinforced polymer plate. Coda Wave Interferometry was used to determine the relative velocity change between a baseline signal taken at room temperature and the signal taken at various temperatures. Three common interferometric algorithms (Cross-Spectral Moving-Window, Windowed Cross-correlation, and Stretching) were used and compared. The influence of several parameters of the experimental configuration, such as the transducer type and aperture size on the results of the processing algorithms was evaluated in order to determine the optimal experimental configuration.**---**This work is supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

References:

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2. Y. Lu, J. E. Michaels, "A methodology for structural health monitoring with diffuse ultrasonic waves in the presence of temperature variations," in *Ultrasonics* **43**, pp. 707-731 (2005).
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4:50 PM

Novel Self-Sensing Carbon Nanotube-Based Composites for Rehabilitation of Structural Steel Members

---Shafique Ahmed[1,4], Sagar Doshi[2,4], **Thomas Schumacher**[1,4], Erik T. Thostenson[2,3,4], Jennifer McConnell[1,4], [1]Department of Civil and Environmental Engineering; [2]Department of Mechanical Engineering; [3]Department of Materials Science Engineering; [4]Center for Composite Materials University of Delaware; Newark, Delaware 19716

---Fatigue and fracture are among the most critical forms of damage in metal structures. Fatigue damage can initiate from minor inherent and unavoidable flaws (e.g., surface scratches, voids in welds, and foreign substrate in the cast metal) and initiate a crack. Under cyclic loading, these cracks can grow and reach a critical level to trigger fracture of the member which can lead, in some cases, to catastrophic failure of the entire structure. In our research, we are investigating a solution using carbon nanotube-based sensing composites, which have the potential to rehabilitate and monitor a fatigue-cracked member simultaneously. These composites consist of a fiber-reinforced polymer (FRP) layer and a sensing layer, which are integrated to form a novel structural self-sensing material. The sensing layer is infused with carbon nanotubes to form a conductive network, which is extremely sensitive to deformations as well as damage accumulation. These correlate to the change of resistance in the CNT network, which can be monitored via electrodes attached to the novel composite material. In this paper, we introduce the central concept, present the manufacturing of a prototype, and discuss a set of small-scale laboratory experiments to examine the load-carrying capacity and damage sensing response of our proposed solution.

WEDNESDAY

WEDNESDAY, JULY 29, 2015

	Session 17 Ultrasonic Arrays I ***Nicollet D1***	**Session 18 NDE of Composites II (Experimental)** ***Nicollet D2***	**Session 19 NDE and NDT Systems and Civil Engineering Materials** ***Nicollet D3***	**Session 20 Signal Processing and New Techniques** ***Lakeshore C***	**Session 21 6th EAW** ***Lakeshore A***
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10:10	COFFEE BREAK				
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	Session 22 Ultrasonic Arrays II and Non-Linear ***Nicollet D1***	**Session 23 NDE Modeling of Composites** ***Nicollet D2***	**Session 24 One-Sided Access for Civil Infrastructure Characterization** ***Nicollet D3***	**Session 25 Sensors** ***Lakeshore C***	**Session 26 6th EAW** ***Lakeshore A***
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Session 17

SESSION 17

ULTRASONIC ARRAYS I

Bob Addison and Paul Wilcox, Co-Chairpersons
Nicollet D1

8:30 AM **Plane Wave Imaging for Ultrasonic Inspection of Irregular Structures with High Frame Rates**
---Léonard Le Jeune[1], **Sébastien Robert[1]**, and Claire Prada[2], [1]CEA LIST, 91191 Gif-sur-Yvette, France: [2]Institut Langevin, 1 rue Jussieu, 75238 Paris Cedex, France

8:50 AM **Fast Total Focusing Method for Ultrasonic Imaging**
---Ewen Carcreff[1], Gavin Dao[2], and **Dominique Braconnier**[1], [1]The Phased Array Company, 9078 Union Centre Blvd. suite 350, West Chester, OH 45069; [2]Advanced OEM Solutions, 8044 Montgomery Rd. 700, Cincinnati, OH 45236

9:10 AM **Imaging Beyond Aliasing**
---**Arno Volker** and Paul van Neer, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, The Netherlands

9:30 AM **Near Surface Imaging Using Diffuse Field Full Matrix Capture**
---**Jack Potter**, Paul D. Wilcox, and Anthony J. Croxford, University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom

9:50 AM **A Novel Serrated Columnar Phased Array Ultrasonic Transducer**
---**Cheng Zou**, Zhenguo Sun, Dong Cai, Hongwei Song, and Qiang Chen, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, China

10:10 AM ***Break***

10:30 AM **Investigation into Angular and Frequency Dependence of Scattering Matrices of Elastodynamic Scatterers**
---**Jie Zhang**[1], Maria Felice[1], Alexander Velichko[1], and Paul D. Wilcox[1]; [1]Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, United Kingdom

10:50 AM **Multiple Scattering Filter: Application to the Plane Defect Detection in a Nickel Alloy Media**
---**Camille Trottier**[1], Sharfine Shahjahan[1], Andreas Schumm[1], Alexandre Aubry[2], and Arnaud Derode[2], [1]EDF R&D – EDF-Lab les Renardieres 77818 Moret sur Loing, France; [2]Institut Langevin – 1 rue Jussieu 75005 paris, France

11:10 AM **Optimal Matched Filter Design for Ultrasonic NDE of Coarse Grain Materials**
---**Minghui Li**[1] and Gordon Hayward[2], [1]School of Engineering, University of Glasgow, Glasgow G12 8QQ, United Kingdom; [2]Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow G1 1XW, United Kingdom

11:30 AM **Finite Element Analysis for Ultrasonic NDE Inspections of Heterogeneous Materials**
---**Jeff Dobson**, Anthony Gachagan, Richard O'Leary, Anthony Mulholland, and Katherine Tant, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Andrew Tweedie and Gerald Harvey, Weidlinger Associates Ltd., Glasgow, United Kingdom

11:50 AM **PAUT Inspection of Copper Canister: Structural Attenuation and POD Formulation**
---A. Gianneo1, M. Carboni1, C. Mueller2, and U. Ronneteg3; 1Dipartimento di Meccanica, ***Politecnico di Milano, Via La Masa 1, 20156 Milano, [2]BAM, Berlin, Germany; [3]SKB, Oskarshamn, Sweden***

12:10 PM ***Lunch***

8:30 AM

Plane Wave Imaging for Ultrasonic Inspection of Irregular Structures with High Frame Rates

---Léonard Le Jeune[1], **Sébastien Robert**[1] and Claire Prada[2] [1]CEA LIST, 91191 Gif-sur-Yvette, France; [2]Institut Langevin, 1 rue Jussieu, 75238 Paris Cedex, France

---Coherent Plane Wave Compounding (CPWC), also known as Plane Wave Imaging (PWI), is a medical imaging method to achieve high frame rates with a reduced speckle noise. Transient elastography or blood flaw imaging with PWI have been studied for nearly a decade, while the full potential of this technique for NDE has not been explored yet. In the PWI method, plane waves are transmitted in several directions in the inspection medium, and, for each transmission, the back-scattered waves are recorded with all the elements of the phased-array probe. The recorded signals are then post-processed with a delay-and-sum algorithm to focus on every point of a region of interest. In the present communication, the PWI method is generalized to immersion-testing configurations (plane or complex water/steel interface between the probe and the image area) and to different imaging modes (imaging with direct or half-skip wave paths, including mode conversions or not…) according to the type of defects (point-like or extended crack-types defects) and their location or orientation. The multimodal PWI method is compared with the Synthetic Transmit Aperture (STA) imaging which is often considered as the reference method in NDE. First, the communication describes the theoretical background of the multimodal PWI method in case of plane and irregular surfaces. Then, experimental PWI results are given and compared with STA images for different testing configurations. Because the high-amplitude plane waves are less sensitive to noise and attenuation than the cylindrical waves transmitted in STA imaging, we demonstrate that it is possible to obtain high quality images with a significantly reduced number of transmissions.

8:50 AM

Fast Total Focusing Method for Ultrasonic Imaging

---**Ewen Carcreff**[1], Gavin Dao[2], and Dominique Braconnier[1], [1]The phased Array Company, 9078 Union Centre Blvd. Suite 350, West Chester, OH 45069; [2]Advanced OEM Solutions, 8044 Montgomery Rd. 700, Cincinnati, OH 45236

---Ultrasound imaging using array transducers is now a mature technique to assess industrial component integrity. The total focusing method is an advanced imaging technique that is optimally focusing at each point of the reconstruction area. This is effected by computing the proper wave travel times at each point and by applying coherent summations over all the array elements. This approach is heuristic but give good results in real applications and generally outperforms conventional phased array imaging. The main drawback of this approach is the computation time which makes real-time imaging difficult for large images. In this communication, we propose to use a migration approach for accelerating the processing [1, 2]. The purpose is to formalize the acquisition modality in the wavenumber domain. We show that this technique is much faster than the heuristic approach and that the signal to noise ratio is largely improved. Figure 1 shows a comparison of both approaches for the imaging of an aluminum block containing side drilled holes. The results presented in this paper demonstrate the potential of this approach for real-time imaging applications.

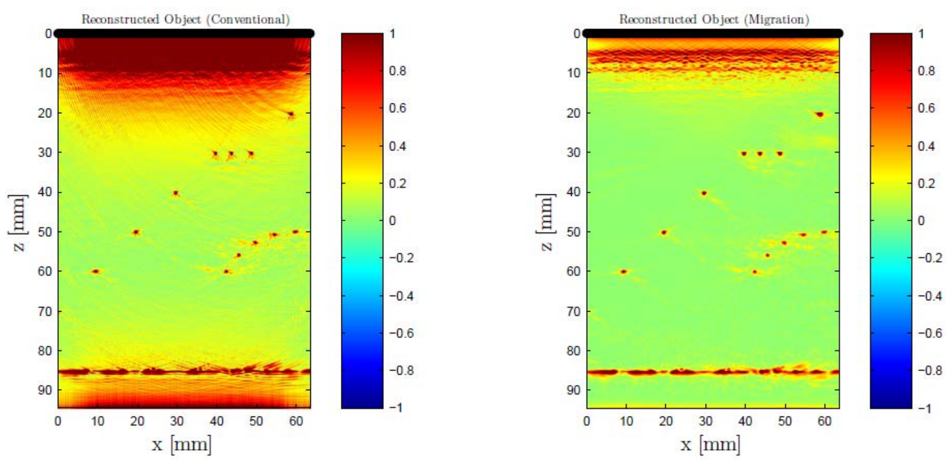

Figure 1. Example of total focusing method imagery of an aluminum block containing 1 mm side drilled holes. Left: Conventional approach, right: migration approach.

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9:10 AM

Imaging Beyond Aliasing

---**Arno Volker** and Paul van Neer, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, The Netherlands

---Proper spatial sampling for high quality imaging is critical. If the sampling criterion is not met, artifacts appear in the image generally referred to as grating lobes. Probes with a large aperture provide a large field of view, which allows for more efficient inspection. On the other hand this leads to an increase in the number of element to obey the sampling criterion. We have developed a method that reconstructs sparsely sampled data without assuming anything about the medium. The reconstruction method involves an iterative scheme using wave field extrapolation. After the reconstruction an aliasing free dataset is obtained which can be imaged properly. Aliased and non-aliased datasets were modeled based on point diffractors and reflectors with an increasing width. The datasets were imaged using a mapping in the wavenumber-frequency domain. Up to a factor four of under-sampling can be tolerated, providing the same image quality as a properly sampled dataset.

9:30 AM

Near Surface Imaging Using Diffuse Field Full Matrix Capture

---**Jack Potter**, Paul D. Wilcox, and Anthony J. Croxford, University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom

---When ultrasonic transducers are directly coupled to a component electrical cross-talk, saturation and surface waves leave the imaging system effectively blind to the near surface. Naturally this may be negated by the use of a stand-off medium, however this is not always practical and limits the energy that may be transmitted to a specimen. Within a bounded system, some sufficient time after the transmission of sound, as a consequence of multiple scattering the field will approach a diffuse state. By applying ensemble-averaging, cross correlation of diffuse fields recorded at two points in the system will yield the coherent heterogeneous Green's function between those points. This can be utilized with ultrasonic arrays by acquiring a full matrix of transmit-receive responses in the diffuse field. Received data for each element-pair may be cross-correlated and averaged over all transmitting elements. Through this process, the diffuse full matrix is converted to the un-delayed coherent version but with the crucial omission of the effects of saturation and electrical cross-talk which were only present at the time of original transmission. The near-surface may be examined much more effectively using this reconstructed full matrix while the rest of the component can still be imaged using a conventionally captured full matrix.

9:50 AM

A Novel Serrated Columnar Phased Array Ultrasonic Transducer

---Cheng Zou, Zhenguo Sun, Dong Cai, Hongwei Song, and Qiang Chen, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, China

---Traditionally, wedges are required for generation of shear waves in a solid specimen and mechanical rotation device is needed for interrogation of a specimen with a hollow bore, such as high speed railway locomotive axles, turbine rotors, etc [1, 2]. In order to get rid of the wedges and eliminate the mechanical rotation process, a novel array pattern of phased array ultrasonic transducers is devised. This pattern is named as serrated columnar phased array ultrasonic transducer, and SCPAUT for short, according to its shape. The elementary transducers are planar rectangular and located on the outside surface of a cylinder. The longer side is parallel to the axis of the cylinder, which is similar to that of a convex or cylindrical array [3]. The key difference between the SCPAUT and the convex array is that the apertures are rotated with a certain angle relative to the tangential surface of the cylinder. This layout is aimed to generate electrically rotating shear waveforms and inspect the longitudinal cracks on the outside surface of the specimen which has a hollow bore, such as the high speed railway locomotive axles. The general geometry of the SCPAUT and the inspection system are illustrated in Figure 1. A part of SCPAUT with 11 transducers has been manufactured. The probe was immersed in the fluid medium and coupled to the inside surface of a hollow specimen. The delayed time laws were calculated under the condition of a curved interface. A longitudinal crack with 1mm depth and 0.35mm width on the outside surface of a hollow axle specimen has been successfully detected.

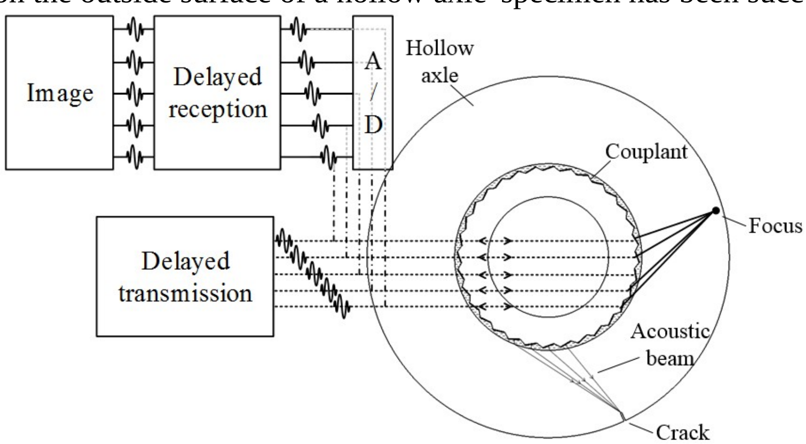

Figure 1. Model of a serrated columnar phased array ultrasonic transducer placed in the center of a hollow axle.

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10:30 AM

Investigation into Angular and Frequency Dependence of Scattering Matrices of Elastodynamic Scatterers

---**Jie Zhang**[1], Maria Felice[1], Alexander Velichko[1] and Paul D. Wilcox[1]; [1]Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, United Kingdom

---The scattering behavior of a finite-sized elastodynamic scatter in a homogeneous isotropic medium can be encapsulated in a scattering matrix (S-matrix) for each mode combination. Each S-matrix is a continuous complex function of 3 variables: incident wave angle, scattered wave angle and frequency. In the paper, the S-matrices for various scatterers (circular hole, straight cracks, cracks with multiple segments and surface-breaking cracks) are investigated. It is shown that, for a given scatterer, the continuous data in the angular dimensions of an S-matrix can be represented to a prescribed level of accuracy by a finite number of complex Fourier coefficients. The finding is that the number of angular orders required to characterize a scatterer is a function of scatterer size and is related to the Nyquist theorem. The variation of scattering behavior with frequency is examined next and is found to show periodic oscillation with a period which is also a function of scatterer size. The shortest period of these oscillations indicates the maximum frequency increment required to accurately describe the scattering behavior in a specific frequency range. Finally, the maximum angular order and frequency increments for the chosen scatterers in a specific frequency range are suggested. One potential use of this information is to determine the number of separate numerical simulations needed to completely characterize the ultrasonic response of a scatterer. The use of such an approach is demonstrated in the context of ultrasonic array data simulation using a hybrid finite-element/ray-tracing model.

10:50 AM

Multiple Scattering Filter: Application to the Plan Defect Detection in a Nickel Alloy Media
---Camille Trottier[1], Sharfine Shahjahan[1], Andreas Schumm[1], Alexandre Aubry[2] and Arnaud Derode[2], [1]EDF R&D – EDF-Lab les Renardières 77818 Moret sur Loing, France ; [2]Institut Langevin – 1 rue Jussieu 75005 Paris, France

---The ultrasonic inspection of polycrystalline media remains a challenge. The high noise levels due to the interaction between the wave and the microstructure limit the efficiency of classical ultrasonic techniques to detect a defect in a coarse grain structure. The aim of this work is to reduce the influence of multiple scattering in order to increase the information obtained from the defect. The new technique introduced in this presentation is based on array probes for the acquisition of the medium's response matrix by full matrix capture, after which a filter based on random matrix theory is applied. Here the technique is used on a nickel alloy block that presents an unfavorable grain structure and a well known plane defect. In this paper, the results of this new technique, with an angle array probe of 128 elements and 5 MHz of central frequency are compared to classical phased array probe techniques.

11:10 AM

Optimal Matched Filter Design for Ultrasonic NDE of Coarse Grain Materials

---Minghui Li[1] and Gordon Hayward[2] [1]School of Engineering, University of Glasgow, Glasgow G12 8QQ, United Kingdom; [2]Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow G1 1XW, United Kingdom

---Ultrasonic inspection and imaging of coarse grain materials is a challenging yet essential problem which has received considerable attention from the NDE community in the recent decades. The flaw echoes are usually contaminated by high-level, correlated noise originating from the microstructure of the tested materials, and the grain noise is time-invariant and demonstrates similar spectral characteristics as flaw signals. A wide variety of techniques have been investigated to suppress grain noise and enhance flaw detection utilizing either the spatial diversity introduced by a transducer array or the time-frequency characteristics of the broadband ultrasonic signals. The signal matching concept has been extensively used in the detection of signals of known form in stationary noise in the application areas like radar and sonar, and more recently in the field of ultrasound NDE. If the signal waveforms and the noise statistics are exactly known *a priori*, the matched filter is optimal in terms of the SNR improvement; this is unfortunately not the case in ultrasonic NDE. Earlier studies use flaw signals obtained from modelling or simulations to design the filter [1, 2], but they are inevitably subject to significant errors, especially in NDE of highly scattering materials. In this paper, we propose an algorithm for optimal matched filter design. The defect echoes are approximated by the superposition of multiple transmitted signals with different phase shift, time delay and amplitude gain that simulates reflections from an unknown extended target. A particle swarm optimization (PSO) paradigm is employed to search for the optimal parameters in the filter response to maximize the SNR improvements over a set of training signals captured from real tests. This matched filter is then applied to the received A-scan signals for further processing and imaging. Experiments with a 128-element 5MHz transducer array on an austenitic stainless steel and a nickel-steel alloy samples are conducted, and the total focusing method (TFM) is used to create the images. It has been demonstrated that the SNR of the images is improved by more than 20dB when the optimized matched filter is applied to all the A-scan waveforms prior to TFM imaging. The method demonstrates good flaw detection in A-scan waveforms as well even when the SNR is pretty low and the level of grain noise is far above that of flaw echoes. The performance advantages are achieved with low extra computational cost of implementation of the matched filters.

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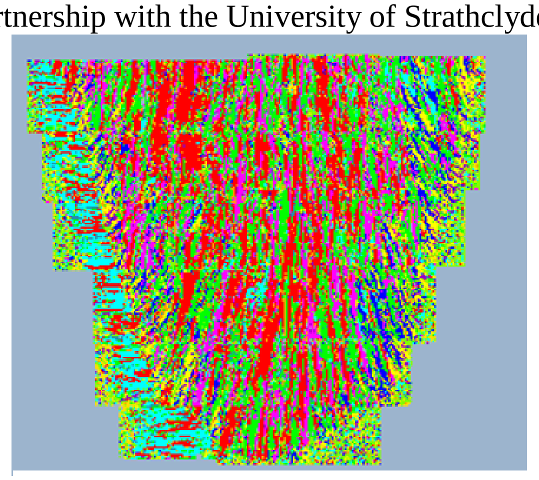
11:30 AM

Finite Element Analysis for Ultrasonic NDE Inspections of Heterogeneous Materials
--Jeff Dobson, Anthony Gachagan, Richard O'Leary, Anthony Mulholland, and Katherine Tant, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Andrew Tweedie and Gerald Harvey, Weidlinger Associates Ltd., Glasgow, United Kingdom

---Advances in manufacturing techniques and materials has seen an increase in the demand for reliable and robust inspection techniques to maintain safety critical features. The application of modelling methods to develop and evaluate inspections is becoming an essential tool for the NDE community. Current analytical methods are inadequate for simulation of arbitrary components and heterogeneous materials, such as anisotropic welds or composite structures. Finite element analysis software (FEA), such as PZFlex, can provide the ability to simulate the inspection of these arrangements, providing the ability to economically prototype and evaluate improved NDE methods. FEA is often seen as computationally expensive for ultrasound problems however, advances in computing power have made it a more viable tool. This work aims to illustrate the capability of appropriate FEA to produce accurate simulations of ultrasonic array inspections. The paper will describe simulation schemes for the validation of array inspections based on the full matrix capture/total focussing method – minimising the requirement for expensive test-piece fabrication. Validation is afforded via corroboration of the FE derived and experimentally generated data sets for a test-block comprising 1D and 2D defects. The modelling approach is extended to consider the more troublesome aspects of heterogeneous materials where defect dimensions can be of the same length scale as the grain structure. The model is used to facilitate the implementation of new ultrasonic array inspection methods for such materials. This is exemplified by considering the simulation of ultrasonic NDE in a weld structure shown in Figure 1 in order to assess new approaches to imaging such structures. This work is funded jointly by the EPSRC and Weidlinger Associates Ltd. for an Engineering Doctorate studentship through the RCNDE (Grant no. EP/I017704/1) and carried out in partnership with the University of Strathclyde.



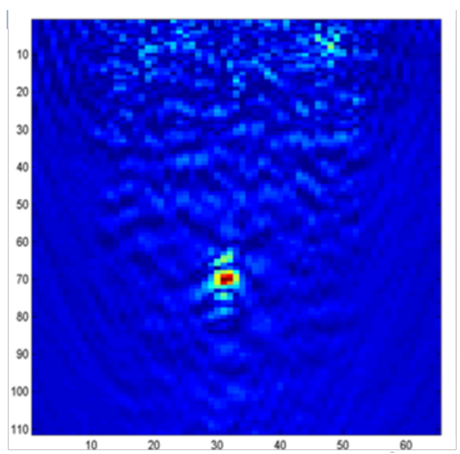


Figure 1: Electron back scatter diffraction data (left) and TFM produced image using data generation from FEA simulated grain model (right) of anisotropic weld.

11:50 AM

PAUT Inspection of Copper Canister: Structural Attenuation and POD Formulation

---A. Gianneo[1], M. Carboni[1], C. Mueller[2], and U. Ronneteg[3]; [1]Dipartimento di Meccanica, Politecnico di Milano, Via La Masa 1, 20156 Milano, [2]BAM, Berlin, Germany; [3]SKB, Oskarshamn, Sweden

---For inspection of thick-walled copper canisters (50mm) for final disposal of spent nuclear fuel in Sweden, ultrasonic inspection using phased array technique (PAUT) is applied. Based on the fact that thick-walled copper not commonly is used as construction material, previous experience on PAUT for this type of application is limited. The paper presents the progress in understanding the amplitudes and attenuation changes acting on the PAUT inspection of the copper canisters. Previous studies showed the existence of a low pass filtering effect, and a heterogeneous grain size distribution along the depth, thus affecting both the detectability of defects and their POD determination. Consequently, the difference between the first and second back wall echoes were not sufficient to determine the local attenuation (within the inspection range), which affects the signal response for each individual defect. Experimental evaluation of structural attenuation was carried out onto step-wedge samples cut from full-size, extruded and pierced & drawn, copper canisters. Effective attenuation values has been implemented in numerical simulation to achieve a Multi Parameter POD and to formulate a Model Assisted POD through a Monte-Carlo extraction model.

Session 18

SESSION 18
NDE of COMPOSITES II (EXPERIMENTAL)
Mahmood Haq and Lalita Udpa, Co-Chairpersons
Nicollet D2

8:30 AM **Air Force Activities Driving NDE of Composites**
---**Sean Coghlan**, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

8:50 AM **Monitoring of Fatigue Damage in Prestressed Composite Lap-Joints Using Guided Waves and FBG Sensors**
---**Oleksii Karpenko**[1], Anton Khomenko[2], Ermias Koricho[2], Mahmoodul Haq[2,3], and Lalita Udpa[1], [1]Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48864; [2]Composite Vehicle Research Center, 2727 Alliance Drive, Lansing, MI 48910, [3]Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48864

9:10 AM **Fast and Broadband Numerical Models for Electromagnetic NDE of Composite Materials**
---**A. Tamburrino**, DIEI, Università degli Studi di Cassino e del Lazio Meridionale, Cassino, 03043, Italy and Michigan State University, East Lansing, MI 48864; C. Forestiere and G. Rubinacci, DIEL, Università di Napoli Federico II, Napoli, 80125, Italy; S. Ventre, DIEI, Università degli Studi di Cassino e del Lazio Meridionale, Cassino, 03043, Italy; C. Ye, L. Udpa, and S. Udpa, Michigan State University, East Lansing, MI 48864

9:30 AM **Design and Demonstration of Automated Data Analysis Algorithms for Ultrasonic Inspection of Complex Composite Panels with Bond**
---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; David S. Forsyth, TRI/Austin, Austin, TX 78746; John T. Welter, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

9:50 AM **Investigation of Ultrasonic Flux Imaging for Damage Detection in Polymer Composites**
---**J. T. Welter**[1], R. W. Martin[2], R. Mooers[1], R. Reibel[2], T. R. Boehnlein[2], and S. Sathish[2], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB OH 45433; [2]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

10:10 AM ***Break***

10:30 AM **Ultrasonic Testing of Composites in the Aircraft Industry**
---**Nicolas Dominguez**, Silvère Barut, and Frank Guibert, Airbus Group Innovations, Toulouse, France; Romain Ecault, TESTIA France, Airbus Group, Toulouse, France

10:50 AM **Accurate Microwave Thickness Evaluation of Liner and Structural Wall Thickness in Fiberglass Composite Structures**
---Mohammad T. Ghasr, Matthew J. Horst, and **R. Zoughi**, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409; Mario Lechuga, R. Rapoza, and C. Renoud, Fiberglass Structural Engineering (FSE), Inc., Bellingham, WA 98226

11:10 AM **Evaluation of Fatigue Damage Accumulation in Composites via Linear and Nonlinear Guided Waves Methods**
---**Jinling Zhao**[1,2], Vamshi Chillara[2], Hwanjeong Cho[2], Jinhao Qiu[1], and Cliff Lissenden[2], [1]State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu 210016, China; [2]Department of Engineering Science and Mechanics, Penn State, University Park, PA 16802

11:30 AM **Acoustic Characterization of Void Distributions Across Carbon-Fibre Composite Layers**
---**Rostand B. Tayong**[1], Robert A. Smith[1], and Valerie J. Pinfield[2], [1]Department of Mechanical Engineering, University of Bristol, University walk, Bristol BS81TR, United Kingdom; [2]Chemical Engineering Department, Loughborough University, Loughborough, Leics. United Kingdom

12:10 PM ***Lunch***

8:30 AM

Air Force Activities Driving NDE of Composites
---**Sean Coghlan**, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---Development systems and future Air Force concepts rely on ever-increasing utilization of advanced composite materials and structures to achieve goals in performance, fuel efficiency, and affordability. There are rapid developments in computational design, modeling, performance analysis, and life prediction of composites which require verification and validation before these tools can be put to widespread use. In addition, challenges are emerging in multi-functional materials where both structural integrity and embedded functionality have to be assessed. Another consideration is the possibility of service life extension of composite structures with mechanically fastened joints, provided tools emerge to evaluate fastener holes when it comes time for service life assessments. This presentation covers the US Air Force goals, technology promises, and challenges that drive future desired NDE capability requirements.

8:50 AM

Monitoring of Fatigue Damage in Prestressed Composite Lap-Joints Using Guided Waves and FBG Sensors

---**Oleksii Karpenko**[1], Anton Khomenko[2], Ermias Koricho[2], Mahmoodul Haq[2,3], and Lalita Udpa[1], [1]Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48864; [2]Composite Vehicle Research Center, 2727 Alliance Drive, Lansing, MI 48910, [3]Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48864

---Adhesive bonding is being increasingly employed in many industrial applications as it offers efficient and durable joining of different materials along with reduction in time and cost of manufacturing. However, joints are mostly considered the ‘weak-links’ of the structure, which necessitates reliable NDE and SHM techniques to ensure their integrity. In this work, a technique based on combination of guided waves and fiber-Brag grating (FBG) sensors is used to monitor fatigue damage in adhesively bonded composite lap-joints. In the current set-up, one FBG sensor is bonded on the surface of the adherend while the other is embedded in the adhesive bond-line of a lap-joint. Full spectral responses of both FBG sensors are measured and compared at specific intervals of fatigue cycles at varying load levels. FBG sensors are also continuously interrogated and data are recorded during the cyclic loading. In parallel, guided waves are actuated and sensed with the help of PZT wafers mounted on the surface of the composite adherends. Experimental results demonstrate that amplitude and time of flight (ToF) of the fundamental modes transmitted through the bond-line and spectral response of FBG sensors are sensitive to fatigue damage and loading conditions. Combination of guided wave and FBG measurements provides the desired redundancy and synergy in the data to evaluate the degradation in bond-line properties and the resulting post-damage stiffness of the joints. Measurements taken in the presence of continuously applied load replicate the in-situ/service conditions. The approach shows promise in understanding the behavior of bonded joints subjected to complex loads.

9:10 AM

Fast and Broadband Numerical Models for Electromagnetic NDE of Composite Materials

---A. Tamburrino, DIEI, Università degli Studi di Cassino e del Lazio Meridionale, Cassino, 03043, Italy and Michigan State University, East Lansing, MI 48864; C. Forestiere and G. Rubinacci, DIEL, Università di Napoli Federico II, Napoli, 80125, Italy; S. Ventre, DIEI, Università degli Studi di Cassino e del Lazio Meridionale, Cassino, 03043, Italy; C. Ye, L. Udpa, and S. Udpa, Michigan State University, East Lansing, MI 48864

---In recent years, the use of composite materials in aeronautical and aerospace industry has experienced significant growth because of their superior weight and lifecycle performances. This has result in a significant demand for reliable Nondestructive Evaluation (NDE) methods for both in manufacturing and in-service inspection of aircrafts. Traditional methods, mainly developed for isotropic materials, may be inadequate when applied to composite (anisotropic) materials. The lack of accepted robust Nondestructive Evaluation (NDE) methods is a contributing factor to the increase in cost and complexity of developing new structural composites. Time-consuming and costly testing procedures are needed to assure a proper level of product safety. In this scenario, numerical modelling of NDE tests is a valuable tool to optimize the design of probes, to understand probe signals, to characterize materials, to detect/image defects, to train technical personnel, for virtual prototyping. This contribution is focused on the development of numerical models and codes for predicting the outcome of a Non Destructive Evaluation (NDE) test of composite materials such as glass fibers (GFRP) and/or carbon fibers (CFRP) reinforced plates, by means of low-frequency electromagnetic fields and probes. Despite the availability of established general purpose numerical simulators for computational electromagnetics, the specialized nature of these NDE problems (multiscale nature, low-computational cost, great accuracy,…) calls for the development of custom designed simulation software. There are very few commercial codes for such specific electromagnetic NDE applications and none is capable of modeling composite materials in a general setting. This paper presents a numerical model that is based on a source integral formulation in term of induced eddy currents density and/or polarization current density. The integral formulation will be combined with a finite element discretization of the problem to guarantee large flexibility in geometry and material descriptions (space varying and tensor constitutive relationships). The basis for the proposed numerical model is in [1] and [2], devoted to isotropic conductive materials. Preliminary experience in modelling composite materials can be found in [3] and [4] where partial results in specific situations (absence of volumetric charge density, absence of the fast solver for repeated computations [2]) have been developed. Here we intend to combine [1]-[4] for achieving a new numerical simulator. Particular attention will be paid to accuracy and speed as key features. Moreover, the simulator will be broadband (from almost static to quasi-static and microwave frequencies). Numerical examples will be presented to prove the effectiveness of the proposed approach.

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9:30 AM

Design and Demonstration of Automated Data Analysis Algorithms for Ultrasonic Inspection of Complex Composite Panels with Bonds

---John C. Aldrin, Computational Tools, Gurnee, IL 60031; David S. Forsyth, TRI/Austin, Austin, TX 78746; John T. Welter, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---To address the data review burden and improve the reliability of the ultrasonic (UT) inspection of large composite structures, automated data analysis (ADA) algorithm and software have been developed to make calls on indications that satisfy the call criteria and minimize false calls [1-2]. The original design of the data analysis task follows standard procedures for analyzing signals for time-of-flight indications and backwall amplitude dropout. However, certain complex composite structures with varying shape, thickness transitions and the presence of bonds can greatly complicate this interpretation process. In this paper, enhancements to the automated data analysis algorithms are introduced to address these challenges. One goal is to estimate the thickness of the part and presence of bonds without prior information. This task is accomplished through tracking potential backwall signals, detecting the presence of multiple signals and step changes which are indicators of bonded sections, and through the application of smart spatial filters for estimating the panel thickness and additional bonded sections with varying signal levels. Once part boundaries, thickness transitions and bonded regions are identified, feature extraction algorithms are applied to multiple sets of through-thickness and backwall C- scan images, for evaluation of both first layer through thickness and layers under bonds. The use of prior part information on panel thickness and bond location is also considered as an option with the algorithm, which would greatly simplify this evaluation process. An intermediate set of test data was selected to challenge the ADA algorithms that includes a wide range of complex parts and artificial defects located both above and below bond lines. Software enhancements were also made to facilitate design studies and support certification. The software can run a set of UT files in batch mode, process the results, compare them to truth tables for each file, and compile the total correct call, missed call, and false call rates for the set. ADA processing results are presented for a variety of test specimens that include inserted materials and discontinuities produced under poor manufacturing conditions. Lastly, improvements to the ADA software interface and automated reporting features will be presented, which improve the software usability with the NDI operator in order to best leverage their expertise in data review as needed.**---**Support for this program was provided through the Defense-Wide Manufacturing Science and Technology Program.

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9:50 AM

Investigation of Ultrasonic Flux Imaging for Damage Detection in Polymer Composites

---J. T. Welter[1], R. W. Martin[2], R. Mooers[1], R. Reibel[2], T. R. Boehnlein[2], and S. Sathish[2], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB OH 45433; [2]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---Materials with anisotropic elastic properties produce three dimensional slowness surfaces with complex shapes. Thus, during acoustic wave propagation in anisotropic materials the amplitude distribution the "ultrasonic flux" could be non-uniform including intensification of acoustic amplitude along certain directions. Measurements of ultrasonic flux distribution and propagation time variation with different directions have been used to determine the elastic constants of single crystals and composite materials. If damage alters the anisotropy of a material, it is expected that the ultrasonic flux distribution will be different in comparison to the undamaged material. Detection and quantitative measurement of these changes in the ultrasonic flux could be useful for nondestructively evaluating damage in materials. This paper describes the experimental measurement of ultrasonic flux distribution consisting of longitudinal and shear waves produced polymer matrix composite sample by a focused acoustic beam. Ultrasonic flux distribution in quasi-isotropic and unidirectional polymer matrix composite specimens before and after cyclic loading is compared. Data analysis methods used to compare the ultrasonic flux distributions and evaluate the damage are described. Limitations of ultrasonic flux imaging in detecting and quantifying damage due to cyclic loading is discussed. Limitations of current ultrasonic models to simulate this type of experiment are presented.

10:30 AM

Ultrasonic Testing of Composites in the Aircraft Industry

---**Nicolas Dominguez**, Silvère Barut, and Frank Guibert, Airbus Group Innovations, Toulouse, France; Romain Ecault, TESTIA France, Airbus Group, Toulouse, France

---Composite materials have taken a central place in last generation aircrafts. While considered almost NDT less in maintenance, composite structures are today the most demanding parts in terms of NDT effort in production. With the increase of aircrafts to be delivered, the challenge not only comes from the quality check itself but also from the productivity of the inspection. For this, actions at all levels of the NDT cycle – NDT design, acquisition and analysis – are implemented to speed up the overall NDT throughput. Design of the NDT configuration is crucial and is generally the time for trade-offs. Simulation is of great help at this stage. Acquisition is also optimized and greatly benefits from advanced phased array capabilities. The analysis with the NDTkit-Ultis software allows to dramatically decreasing the analysis time. In maintenance, NDT of composites is mainly related to impact damages. For that a dedicated tool – the LineTool - has been developed as a go-no go testing allowing quick release of aircrafts when possible. This paper presents examples of realizations on ultrasonic testing for composites developed at Airbus Group for aircrafts application.

10:50 AM

Accurate Microwave Thickness Evaluation of Liner and Structural Wall Thickness in Fiberglass Composite Structures

---Mohammad T. Ghasr, Matthew J. Horst, and **R. Zoughi**, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409; Mario Lechuga, R. Rapoza, and C. Renoud, Fiberglass Structural Engineering (FSE), Inc., Bellingham, WA 98226

---Fiberglass is increasingly used for a number of applications involving chemical storage and transport (i.e., tanks and pipes). From a composite structure point-of-view, fiberglass structures vary in the degree of structural complexity depending on the application for which they are used. In corrosion resistant applications, fiberglass laminate typically consists of a structural layer and a corrosion resistant layer (commonly referred to as the liner) on the inside of the laminate. Liners protect against corrosive chemical attack on the structural layers of the fiberglass. Over time and while in service the liner thickness reduces and its ability to act as a corrosion-resistant layer is markedly diminished. Consequently, the ability to measure fiberglass thickness from outside of a tank or a pipe and during the normal operation of the equipment, quickly and easily with high measurement accuracy, is extremely important for health and life assessment and prediction. Microwave nondestructive techniques, employing open-ended rectangular waveguides, in conjunction with robust and full-wave electromagnetic models, have tremendous potential and viability for evaluating geometrical (i.e., thickness) and dielectric properties of individual layers in a complex layered dielectric composite structure [1, 2]. In this presentation we describe the foundation of this technique, processes involved in optimizing the approach for layered fiberglass evaluation, as well as a number of representative and diverse measurement results demonstrating the efficacy of the techniques and the thickness accuracy that can be obtained. Important issues such as curvature of a structure and water with different temperatures filling it will also be addressed showing that they do not adversely affect liner thickness measurement accuracy**.****---**Funding for this work was provided by Fiberglass Structural Engineering (FSE), Inc., Bellingham, WA, 98226.

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11:10 AM

Evaluation of Fatigue Damage Accumulation in Composites via Linear and Nonlinear Guided Waves Methods

---Jinling Zhao[1,2], Vamshi Chillara[2], Hwanjeong Cho[2], Jinhao Qiu[1], and Cliff Lissenden[2]

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---Stress-induced fatigue damage of composites is a form of material degradation and thus threatens the safety of composite structures. Ultrasonic guided waves based non-destructive evaluation of the damage accumulation in composites during the fatigue process is hence of considerable current interest. This research studied the relationship between three linear parameters and the fatigue loading cycles of composite specimens and the possibility of using nonlinear Lamb waves for early detection of micro-damage. For the linear Lamb waves approach, the laser-generation based imaging system (LGBI) is utilized to measure the phase velocities of composite fatigue specimens. The elastic moduli of the specimen are then reconstructed by inverting the phase velocities using genetic algorithms (GAs). The above two characteristic parameters (phase velocity and elastic moduli), in addition to the Lamb wave amplitudes, are then observed during the fatigue process. Nonlinear Lamb waves in composites are analyzed from a theoretical standpoint. The third-order strain energy function of a transversely isotropic material is expressed by five invariants of the Green-Lagrange strain tensor. Results enable intelligent selection of primary modes and frequencies and show that only cumulative symmetric Lamb second harmonic modes can be generated. Meanwhile, finite element simulations using COMSOL are conducted to analyze the cumulative second harmonics in a transversely isotropic plate when the primary mode is propagating.

11:30 AM

Acoustic Characterization of Void Distributions Across Carbon-Fibre Composite Layers

---**Rostand B. Tayong**[1], Robert A. Smith[1], and Valerie J. Pinfield[2], [1]Department of Mechanical Engineering, University of Bristol, University walk, Bristol BS81TR, United Kingdom; [2]Chemical Engineering Department, Loughborough University, Loughborough, Leics. United Kingdom

--Carbon Fibre Reinforced Polymer (CFRP) composites are often used as aircraft structural components, mostly due to their superior mechanical properties. In order to improve the efficiency of these structures, it is important to detect and characterize any defects occurring during the manufacturing process, removing the need to mitigate the risk of defects through increased thicknesses of structure. Such defects include porosity, which is well-known to reduce the mechanical performance of composite structures, particularly the inter-laminar shear strength. Previous work by the authors has considered the determination of porosity distributions in a fibre-metal laminate structure [1]. This paper investigates the use of wave-propagation modelling to invert the ultrasonic response and characterize the void distribution plies of a CFRP structure. Direct numerical simulations from a finite-element (FE) code are used, modified to allow for a typical transducer's response, as input data to simulate the ultrasonic response of a porous composite laminate. This is then inverted to calculate the distribution of porosity in the layers. The inversion method is multi-dimensional optimization utilizing an analytical model based on a normal-incidence plane-wave recursive method and appropriate mixture rules to estimate the acoustical properties of the structure, including the effects of plies and porosity. Although a single-scattering approach is applied in this initial study, the limitations of the method in terms of percentage porosity and void radius are discussed in relation to between single- and multiple-scattering methods. Both the frequency- and time-domain results are analyzed in this work. A comparison between the inverted and correct FE-modelled parameters is made and discussed. This work supports the general study of the use of ultrasound methods with inversion to characterize material properties in three dimensions and any defects occurring in composites structures.---This research is part of a Fellowship in Manufacturing funded by the UK Engineering and Physical Sciences Research Council (EPSRC) aimed at underpinning the design of more efficient composite structures and reducing the environmental impact of travel.

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Session 19

SESSION 19

NDE AND NDT SYSTEMS AND CIVIL ENGINEERING MATERIALS

Dwight Clayton and Halil Ceylan, Co-Chairpersons
Nicollet D3

8:30 AM **Improved SAFT Results of Thick Concrete Specimens Through Frequency Banding**
---**Dwight Clayton**, Alan Barker, Austin Albright, and Hector Santos-Villalobos, Oak Ridge National Laboratory, P. O. Box 2008, MS6174, Oak Ridge, TN 37831-6174

8:50 AM **Development of Acoustic Model-Based Iterative Reconstruction Technique for Thick Concrete Imaging**
---Hani Almansouri[1], Dwight Clayton[2], Roger Kisner[2], Yarom Polsky[2], Charles Bouman[1], and **Hector Santos-Villalobos**[2], [1]Purdue University; [2]Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831-6075

9:10 AM **Inspection of a Thick Concrete Block Containing Embedded Defects Using Ground Penetrating Radar**
---**David Eisenmann**, Frank Margetan, and Lucas Koester, Iowa State University, Center for Nondestructive Evaluation,1915 Scholl Road, Ames, IA 50011; Dwight Clayton, Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831-6174

9:30 AM **Classification of Alkali-Silica Reaction Distress Using Acoustic Emission**
---Mohamed ElBatanouny[2], Rafal Anay[1], Marwa Abdelrahman[1], Jeremiah Fasl[2], Carl Larosche[2], and **Paul Ziehl**[1], [1]Department of Civil and Environmental Engineering, University of South Carolina, Columbia, SC 29208; [2]Wiss, Janney, Elstner Associates, Inc., Austin, TX

9:50 AM **Percolation Models of Alkali Silica Reaction in Concrete Structures**
---**Andrei V. Gribok**[1], Vivek Agarwal[1], and Guowei Cai[2], [1]Department of Human Factors, Controls, and Statistics, Idaho National Laboratory, Idaho Falls, ID 83415; [2]Department of Civil and Environmental Engineering, Vanderbilt University, Nashville, TN 37235

10:10 AM ***Break***

10:30 AM **Effects of Material Properties on Linear and Nonlinear Vibration Responses of Cement and Concrete**
---**John S. Popovics**[1], Jesus N. Eiras[2], and Jeevaka I. Somaratna[1], [1]The University of Illinois at Urbana-Champaign, Urbana, IL 61801; [2]Instituto de Ciencia y Tecnología del Hormigón (ICITECH), Universitat Politècnica de València, 46022 Camino Vera s/n, València, Spain

10:50 AM **Damage Characterization in Concrete Using Nonlinear Surface Acoustic Waves: Detection of Inherent Defects and Microscale Alterations Due to Environmental Interaction**
---**Gun Kim**[1], Jin-Yeon Kim[1], Kimberly E. Kurtis[1], and Laurence J. Jacobs[1,2]; [1]Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; [2]Georgia Institute of Technology, GW Woodruff School of Mechanical Engineering, Atlanta, GA 30332

11:10 AM **Multi-Resolution Analysis and Reconstruction of Ultrasonic Signals**
---**Vivek Agarwal** and Andrei V. Gribok, Idaho National Laboratory, Department of Human Factors, Controls, and Statistics, Idaho Falls, ID

11:30 AM **Damage Detection of Wind Turbine Blades Using a Root Based Network of Thin Film Sensors**
---**Austin Downey**[1,2] and Simon Laflamme[1,3]; [1]Department of Civil, Construction, and Environmental Engineering, Iowa State University, Ames, IA, 50011; [2]Department of Wind Energy Science Engineering and Policy, Iowa State University, Ames, IA, 50011; [3]Department of Electrical and Computer Engineering, Iowa State University, Ames, IA, 50011

11:50 AM **A Pipe Inspection System by a Guidewave Using a Long Distance Waveguide**
---**Riichi Murayama**, Kenshi Matsymoto, and Kenji Ushitani, Faculty of Engineering, Fukuoka Institute of Technology, 3-30-1 Wazirohigashi, Higashi, Fukuoka, 811-0295 Japan; Makiko Kobayashi, Faculty of Engineering, Kumamoto University, 2-40-1 Kurokami Chuo-ku, Kumamoto City, 860-8555 Japan

12:10 PM ***Lunch***

8:30 AM

Improved SAFT Results of Thick Concrete Specimens Through Frequency Banding

---Dwight Clayton, Alan Barker, Austin Albright, and Hector Santos-Villalobos, Oak Ridge National Laboratory, P. O. Box 2008, MS6174, Oak Ridge, TN 37831-6174

---A multitude of concrete-based structures are typically part of a light water reactor (LWR) plant to provide the foundation, support, shielding, and containment functions. Concrete has been used in the construction of nuclear power plants (NPPs) because of three primary properties; its inexpensiveness, structural strength, and ability to shield radiation. Examples of concrete structures important to the safety of LWR plants include the containment building, spent fuel pool, and cooling towers. This use has made its long-term performance crucial for the safe operation of commercial NPPs. Extending reactor life to 60 years and beyond will likely increase susceptibility and severity of known forms of degradation. Additionally, new mechanisms of materials degradation are also possible. There are various instruments available for the inspection of concrete structures that can be used with confidence for detecting different defects. However, more often than not that confidence is heavily dependent on the experience of the operator rather than the clear, objective discernibility of the output of the instrument. The challenge of objective discernment is amplified when the concrete structures contain multiple layers of reinforcement, are of significant thickness, or both, such as concrete structures in nuclear power plants. We seek to improve and extend the usefulness of results produced using the synthetic aperture focusing technique (SAFT) on ultrasonic data collected from thick, complex concrete structures. With the additional goal of improving existing SAFT results, with regards to repeatedly and objectively identifying defects and/or internal structure of concrete structures. Towards these goals, we apply the time-frequency technique of wavelet packet decomposition and reconstruction using a mother wavelet that possesses the exact reconstruction property. However, instead of analyzing the coefficients of each decomposition node, we select and reconstruct specific nodes based on the frequency band it contains to produce a frequency band specific time-series representation. SAFT is then applied to these frequency specific reconstructions allowing SAFT to be used to visualize the reflectivity of a frequency band and that band's interaction with the contents of the concrete structure. Specially designed and fabricated test specimens can provide realistic flaws that are similar to actual flaws in terms of how they interact with a particular NDE technique. Artificial test blocks allow the isolation of certain testing problems as well as the variation of certain parameters. Because conditions in the laboratory are controlled, the number of unknown variables can be decreased, making it possible to focus on specific aspects, investigate them in detail, and gain further information on the capabilities and limitations of each method. To minimize artifacts caused by boundary effects, the dimensions of the specimens should not be too compact. In this paper, we apply this enhanced SAFT technique to a 2.134 m x 2.134 m x 1.016 m concrete test specimen with twenty deliberately embedded defects.**---**The work is funded by the U.S. Department of Energy's office of Nuclear Energy under the Light Water Reactor Sustainability (LWRS) program. The authors would like to acknowledge generous support of the U.S. Department of Energy.

8:50 AM

Development of Acoustic Model-Based Iterative Reconstruction Technique for Thick Concrete Imaging

---**Hani Almansouri**[1], Dwight Clayton[2], Roger Kisner[2], Yarom Polsky[2], Charles Bouman[1], and Hector Santos-Villalobos[2], [1]Purdue University; [2]Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831-6075

---All commercial nuclear power plants (NPPs) in the United States contain concrete structures. Typical concrete structures in these plants can be grouped into four general categories: primary containment buildings, containment internal structures, secondary containments/reactor buildings, and other structures, such as spent fuel pools and cooling towers. These structures provide important foundation, support, shielding, and containment functions. Identification and management of aging and degradation of concrete structures is fundamental to the proposed long-term operation of NPPs. Replacement of concrete structures is impractical; therefore, it is necessary that any safety issues related to plant aging and the acceptability of concrete structures for supporting long-term plant operations are resolved using sound scientific and engineering understanding. Unlike most metallic materials, reinforced concrete is a nonhomogeneous material, a composite with a low-density matrix, a mixture of cement, sand, aggregate and water, and a high-density reinforcement (typically 5% in NPP containment structures), made up of steel rebar or tendons. Concrete structures in NPPs have typically been built with local cement and aggregate fulfilling the design specification regarding material strength, workability and durability; therefore, each plant's concrete composition is unique and complex. In addition, concrete structures in NPPs are often inaccessible and contain large volumes of massively thick concrete. While acoustic imaging using synthetic aperture focusing technique (SAFT) works adequately well for thin specimens of concrete such as concrete transportation structures, enhancements are needed for heavily reinforced, thick concrete. Model-Based Iterative Reconstruction (MBIR) is an image reconstruction framework that embraces the integrated imaging philosophy, where the hardware and software are tailored to provide the ***most informative*** measurement. The method has been applied to the reconstruction of X-ray Computed Tomography (CT) with a superior image quality than state-of-the-art filter back projection techniques. MBIR shows equivalent image quality even after X-ray dose reductions of up to 80%. This reduction in X-ray dose is a testament of the robustness of the system in the presence of noise and sparse information collection, which are usually the interrogation conditions for thick concrete. Consequently, we are pioneering the first implementation of the MBIR algorithm for ultrasound signals. In contrast to delay-and-sum approaches like SAFT, where reconstructed pixel intensities are an integration of signal amplitudes under poor wave propagation assumptions (i.e., constant acoustic speed), our end goal is to include in MBIR comprehensive models for the acoustic system and media (e.g., approximations of wave propagation models for longitudinal and shear waves that include changes in acoustic speed throughout the media). In addition, MBIR will iterate until it finds the intensity reflectivity coefficients distribution over the field of view that best fits the data. We hypothesize that the iterative technique will produce images that are easier to interpret. For this first implementation, we will define a forward model for acoustic p-wave propagation from an ultrasonic phased array with the following assumptions: the media is homogenous, and the Born approximation and coherent integration hold. The paper will include a detailed description of the forward, inverted, and discretized models. In addition, a k-space pseudo-spectral acoustic simulation method will be used to generate an ultrasound dataset to assess the performance of MBIR against state-of-the-art SAFT.---The work is funded by the U.S. Department of Energy's staff office of the Under Secretary for Science and Energy under the Subsurface Technology and Engineering Research, Development, and Demonstration (SubTER) Crosscut program, and the office of Nuclear Energy under the Light Water Reactor Sustainability (LWRS) program. The authors would like to acknowledge the generous support of the U.S. Department of Energy.

9:10 AM

Inspection of a Thick Concrete Block Containing Embedded Defects Using Ground Penetrating Radar

---**David Eisenmann**, Frank Margetan, and Lucas Koester, Iowa State University, Center for Nondestructive Evaluation,1915 Scholl Road, Ames, IA 50011; Dwight Clayton, Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831-6174

---Ground penetrating radar (GPR), also known as impulse response radar, will be used to examine a thick concrete block containing rebar and embedded defects. The block located at the University of Minnesota measures approximately 7 feet tall by 7 feet wide by 40 inches deep, and is intended to simulate certain aspects of a concrete containment wall at a nuclear power plant. The inspections will make use of both pulse/echo and through-transmission setups for data acquisition. For pulse/echo setups, multiple line scans of the block (yielding GPR B-scans) will be made using antennas having three different center frequencies (400 MHz, 900 MHz and 1600 MHz). In addition to the pulse/echo B-scans, a pulse/echo 3-D scan will be conducted using each of the two higher-frequency antennas from both principal sides of the block. Through-transmission line scans will be attempted using a matched pair of 900 or 1600 MHz antennas, respectively. For each embedded defect and reinforcing steel response, the reflected amplitude and time-of-flight (TOF) will be extracted from the data. Tabulated amplitudes and TOF values will make use of both the raw B-scan data and data processed using synthetic aperture focusing techniques (SAFT). This paper will document the relative detectability of the internal reflectors within the block (both rebar and other reflectors) and determine the optimal inspection configuration for each.

9:30 AM

Classification of Alkali-Silica Reaction Distress Using Acoustic Emission

---Mohamed ElBatanouny[2], Rafal Anay[1], Marwa Abdelrahman[1], Jeremiah Fasl[2], Carl Larosche[2], and **Paul Ziehl**[1], [1]Department of Civil and Environmental Engineering, University of South Carolina, Columbia, SC 29208; [2]Wiss, Janney, Elstner Associates, Inc., Austin, TX

---The Nuclear Regulatory Commission regulates a 100 commercial nuclear power reactor that contributes about 20% of the total electric energy produced in the United States. Half of these reactor facilities are over 30 years old and are approaching their original design service life. Due to economic and durability considerations, significant portions of many of the facilities were constructed with reinforced concrete, including the containment facilities, cooling towers, and foundations. While most of these concrete facilities have performed exceptionally well throughout their initial expected service life, some are beginning to exhibit different forms of concrete deterioration. The Seabrook Nuclear Power Plant is exhibiting cracks from alkali-silica reaction (ASR) which brought deterioration of reinforced concrete to the attention of the general public. ASR is a material dependent concrete deterioration mechanism. The reaction initiates if aggregates with reactive silica are present in the high alkalinity medium of concrete. An expansive gel is formed which swells in the presence of moisture causing cracking in the aggregates and the concrete and increase in the total volume of the structure. In this study, acoustic emission (AE) is used to monitor ASR distress during an accelerated ASR test setup. The test program includes 12 specimens created with reactive aggregates and placed in a controlled environment to promote the reaction. The specimens were continuously monitored with AE and length change measurements were taken at discrete time intervals. Visual inspections and petrographic examination were also conducted to relate AE measurements to quantifiable damage states. The results show that AE can detect micro-cracks forming as a result of ASR distress and classify the degree of damage in the specimens. Classification of AE data based on signal processing techniques is also presented. Other ongoing studies related to related degradation mechanisms, including corroiosn, are also discussed.

9:50 AM

Percolation Models of Alkali Silica Reaction in Concrete Structures

---**Andrei V. Gribok**[1], Vivek Agarwal[1], and Guowei Cai[2] [1]Department of Human Factors, Controls, and Statistics, Idaho National Laboratory, Idaho Falls, ID 83415; [2]Department of Civil and Environmental Engineering, Vanderbilt University, Nashville, TN37235

---Alkali silica reaction (ASR) has recently been an area of growing concern in aging concrete structures of operating nuclear power plants [1]. The degradation caused by the reaction affects all concrete structures in nuclear power plants ranging from buildings to spent fuel storage. To effectively understand the impact of the degradation and to estimate remaining useful life of concrete structures, modeling tools are required which can capture the propagation of damage under ASR conditions. In this paper, a simple percolation model [2] is studied to see if it can capture the nature of the ASR propagation. Figure 1 compares a simulated percolation model [3] with a concrete pavement affected by ASR. Notice, the similar structure of percolating clusters in both pictures. The chemical models for the ASR have been actively researched during the last several decades. However, the processes involved in ASR are very complex and they are affected by many factors. This is the reason behind this modeling effort, because the percolation model does not depend on mechanisms of crack formation, the dimensionality of the process or its chemistry. We aim to develop percolation models of multiple fractures where the destruction is the consequence of merging several micro cracks into a large percolating cluster, which ultimately leads to the structure failure. The existence of the percolation threshold is important to predict transition between stable and unstable configurations. We study several percolation lattices to see which lattice most closely reflects the existing experimental data on ASR propagation. The conclusions about applicability of the percolation model to ASR development are drawn and future research efforts are outlined.--- This research is funded by the U.S. Department of Energy under the Light Water Reactor Sustainability Program's Advanced Instrumentation, Information, and Control Technologies Pathway.

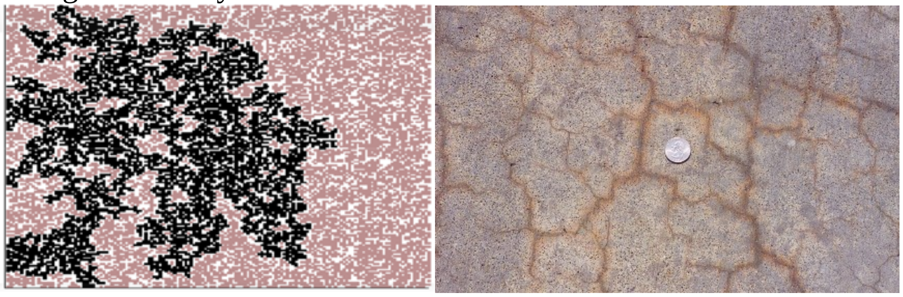

Figure 1. Percolation model on square lattice [3] (left) and alkali silica reaction in concrete (right).

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10:30 AM

Effects of Material Properties on Linear and Nonlinear Vibration Responses of Cement and Concrete

---**John S. Popovics**[1], Jesus N. Eiras[2], and Jeevaka I. Somaratna[1], [1]The University of Illinois at Urbana-Champaign, Urbana, IL 61801; [2]Instituto de Ciencia y Tecnología del Hormigón (ICITECH), Universitat Politècnica de València, 46022 Camino Vera s/n, València, Spain

---Linear and non-linear resonant vibration measurements, carried out on standard test samples, have been shown to be useful for characterizing microstructural changes owing to the presence and extent of internal damage in cement and concrete. Such measurements can monitor distributed cracking damage caused, for example, by freezing and thawing action, alkali-silica reaction, or prolonged high temperature (drying) exposure. However, it is known that the internal moisture content of concrete, which is a porous material, can significantly affect the vibration characteristics of the sample. Here we report results from experimental studies on the effect of internal moisture content on the vibration responses in an effort to distinguish the contribution of damage from that owing to moisture. Linear (resonant frequency, half power bandwidth damping) and nonlinear (amplitude-dependent hysteretic response) vibration measurements, carried out on prismatic cement paste and mortar samples are reported. The samples represent several different mixture compositions and contain varying amount of damage and internal moisture content. The linear measurements are carried out following standard procedures, while the nonlinear responses are obtained using a moving window regime on a single transient time domain response. The linear response data reveal that the change in resonant frequency is significantly affected by internal material moisture content, and the effects of moisture and damage (distributed material microcracking) cannot always be clearly distinguished. The linear resonant responses owing to drying and wetting in undamaged samples shows hysteretic behavior that is recoverable, and likely not a result of microstructural changes, and furthermore the material moisture content of the outer skin region of the samples appears to influence the vibration response more than that in the core. The non-linear hysteretic data, on the other hand, demonstrate sensitivity to microstructural modification and cracking damage, but at the same time are not notably sensitive to pore moisture content, and concrete composition.

10:50 AM

Damage Characterization in Concrete Using Nonlinear Surface Acoustic Waves: Detection of Inherent Defects and Microscale Alterations Due to Environmental Interaction

---**Gun Kim**[1], Jin-Yeon Kim[1], Kimberly E. Kurtis[1], and Laurence J. Jacobs[1,2]; [1]Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; [2]Georgia Institute of Technology, GW Woodruff School of Mechanical Engineering, Atlanta, GA 30332

---Concrete exhibits strong nonlinear acoustic behavior that originates from its complex microstructural characteristics at multiple length scales (from cm to nm). The nonlinear behavior is observed in a number of ways such as harmonic generation, nonlinear mixing, shift in resonance frequencies, and damping parameter, etc. This research exploits the harmonic generation characteristic in propagating Rayleigh waves to evaluate microstructure evolution/damage in a concrete specimen. A measurement setup that uses a wedge transmitter (50 kHz) and a non-contact air-coupled receiver (100 kHz) is proposed – the material nonlinearity is acoustically obtained using the measured fundamental and second harmonic amplitudes with the propagation distance. The acoustic nonlinearity parameter is both assessed as a measure of varying levels of inherent microscale defects, and as influenced by environmental interactions. The results show that the acoustic nonlinearity parameter has capability to sensitively evaluate the initial damage state and to nondestructively perform in situ inspection of concrete components.

11:10 AM

Multi-Resolution Analysis and Reconstruction of Ultrasonic Signals

---**Vivek Agarwal** and Andrei V. Gribok, Idaho National Laboratory, Department of Human Factors, Controls, and Statistics, Idaho Falls, ID 83415

---Acoustic (ultrasonic) array imaging is a technique used in engineering and medicine to allow localization and characterization of objects by generating an acoustic scattered field. An array of sensors facilitates this task since the diversity introduced by transmitting and receiving acoustic energy from many positions enables localization of the scatter. It is for this reason, acoustic imaging technique, i.e., ultrasonic imaging, is used to study degradation in concrete structures in nuclear power plants (NPPs). In this paper, the ultrasonic array data collected using the MIRA version 1 system [1] on a concrete test specimen (typical of a NPP concrete structure) by Oak Ridge National Laboratory [2, 3] will be used to perform multi-resolution analysis. The paper will present time-frequency analysis with Synthetic Aperture Focusing Technique (SAFT). SAFT is an image reconstruction technique commonly used in conjunction with ultrasonic array. As part of the time-frequency analysis, Clayton et al. [2] performed wavelet decomposition with SAFT. This paper will present the short-time Fourier transform (STFT) of original ultrasound signals. Following STFT analysis and empirical mode decomposition (EMD) techniques [4] will be performed on original ultrasound signal. EMD is a data-driven technique that decomposes the original signal into several frequency bands known as intrinsic mode functions (IMFs). Selected IMFs will be reconstructed using SAFT. The outcomes of this research will be compared with the results presented by Clayton et al. [2].---This research is funded by the U.S. Department of Energy under the Light Water Reactor Sustainability Program's Advanced Instrumentation, Information, and Control Technologies Pathway. We also thank Oak Ridge National Laboratory for providing the data analyzed in this paper.

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11:30 AM

Damage Detection of Wind Turbine Blades Using a Root Based Network of Thin Film Sensors

---**Austin Downey**[1,2] and Simon Laflamme[1,3]; [1]Department of Civil, Construction, and Environmental Engineering, Iowa State University, Ames, IA, 50011; [2]Department of Wind Energy Science Engineering and Policy, Iowa State University, Ames, IA, 50011; [3]Department of Electrical and Computer Engineering, Iowa State University, Ames, IA, 50011

---The authors have proposed a capacitive-based thin film sensor for the monitoring of strain on meso-surfaces. When arranged in a network configuration, the sensor allows for the implementation of a global strain sensing system via the monitoring of local strains. The measurement principle for the capacitor is based on the measurable change in capacitance provoked by a change in the sensor's geometry. In the case of bi-directional in-plane strain, the sensor measures the summation of both principal strain components. Because the sensor is highly flexible, it can be applied over rounded surfaces. In this paper, the authors demonstrate that the novel sensing system can be deployed to the root of a horizontal wind turbine blade to quantify the surface strain of non-planar surfaces. Measurements are used to detect local damage on the root section. A numerical simulation of a 40 meter blade was performed using the finite element method, which included various health states. Experimental results demonstrate the capability of the sensor at monitoring blade condition when arranged in a network configuration mounted onto the inside surface a wind turbines blade root. The development of the SEC technology is supported by grant No. 1001062565 from the Iowa Alliance for Wind Innovation and Novel Development and grant No. 13-02 from the Iowa Energy Center. Their support is gratefully acknowledged.---The work reported in this paper is funded under the U.S. National Science Foundation Grant No. 4782025 which supports the activities of the Integrative Graduate Education and Research Traineeship (IGERT) in Wind Energy Science, Engineering and Policy (WESEP) at Iowa State University.

11:50 AM

A Pipe Inspection System by a Guidewave Using a Long Distance Waveguide

---**Riichi Murayama**, Kenshi Matsymoto, and Kenji Ushitani, Faculty of Engineering, Fukuoka Institute of Technology, 3-30-1 Wazirohigashi, Higashi, Fukuoka, 811-0295 Japan; Makiko Kobayashi, Faculty of Engineering, Kumamoto University, 2-40-1 Kurokami Chuo-ku, Kumamoto City, 860-8555 JAPAN

---Nondestructive inspection of a high-temperature structure is required to guarantee its safety. However, there are no useful sensors for high-temperature structures. Some of them cannot operate at temperatures over 50℃.Another concern is that they are too expensive to use. Therefore, a sensing system, which can transmit and receive an ultrasonic wave and travel a long distance using a long waveguide, has been studied. This means that an ultrasonic sensor could be driven at atmospheric temperature. We could finally confirm that a guided ultrasonic wave generated by the developed electromagnetic acoustic transducer (EMAT) can travel more than 10m using a thin rectangular-shaped steel sheet as the waveguide. Next, we tried to transmit and receive a waveguide into a pipe using the long distance waveguide for inspecting high temperature pipes. Actually, the other end of the wave guide was wound in a circumferential direction around the pipe surface using a fixture equipment and adhesive. It has been confirmed that the signal received by the L-mode and T-mode guidewave, which was traveling in the axis direction into a pipe, could be detected by the special shaped waveguides and a drilled hole with a 10mm diameter machined into a pipe could be also detected. The results indicated that the developed technology could be applied to a high temperature pipe in a nuclear power plant.

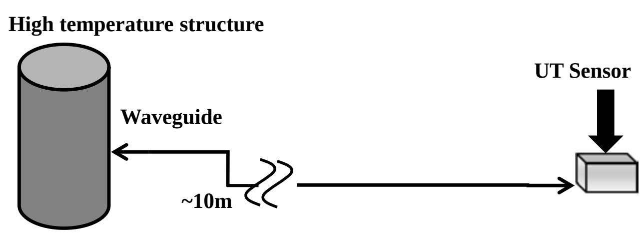

Figure 1. Ultrasonic inspection idea using using a long waveguide for high temperature structure.

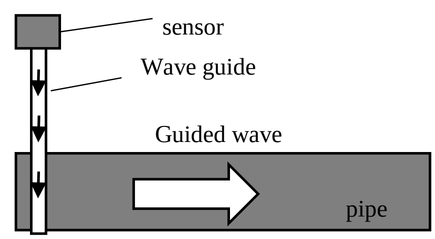

Figure 2. Pipe inspection method using the special shaped waveguide.

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Session 20

SESSION 20
SIGNAL PROCESSING AND NEW TECHNIQUES
Aleksander Dogandzic, Chairperson
Lakeshore C

8:30 AM **Enhancing Pulsed Eddy Current for Inspection of P-3 Orion Lap-Joint Structures**
---**D. M. Butt**[1], P. R. Underhill[2] and T. W. Krause[2], [1]Department of Chemistry and Chemical Engineering, Royal Military College of Canada, Kingston ON K7K 7B4, Canada; [2]Department of Physics, Royal Military College of Canada, Kingston ON K7K 7B4, Canada

8:50 AM **A Model-Based Change Index for Damage Mapping**
---V. John Mathews**, Joel Harley**, University of Utah, Department of Electrical & Computer Engineering, Salt Lake City, UT 84112-9206

9:10 AM **Evaluation and Reconstruction of Wave Features in Wind-Driven Water Film Flow Using Ultrasonic Pulse-Echo Technique**
---**Yang Liu**[1], Leonard J. Bond[1,2], and Hui Hu[1], [1]Iowa State University, Department of Aerospace Engineering, 2271 Howe Hall, Room 1200, Ames, IA 50011; [2]Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, 151 ASC II, Ames, IA 50011

9:30 AM **Ensemble of Classifiers for Confidence-Rated Classification of NDE Signal**
---**Portia Banerjee**, Seyed Safdarnejad, Lalita Udpa, and Satish Udpa, Michigan State University, Non Destructive Evaluation Laboratory, Department of Electrical and Computer Engineering, East Lansing, MI 48824

9:50 AM **A Robust Multi-frequency Mixing Algorithm for Suppression of Rivet Signal in GMR Inspection of Riveted Structures**
---S. Safdarnejad, **O. Karpenko**, L. Udpa, and S. S. Udpa, Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48824

10:10 AM ***Break***

10:30 AM **Modeling of Ultrasonic Guided Waves for Circular Cylindrical Structures Using Finite Element Approach and Selection of Noise Filtering Technique**
---**Ambuj Sharma**[1], Mayank Nirbhay[2], and Amit Tyagi[1]; [1]Mechanical Engineering Department, IIT (BHU) Varanasi-221005, India; [2]Deparatment of Mechanical Engineering, GBU, Greater Noida-201308, India

10:50 AM **Application of Temporal Moments and Other Signal Processing Algorithms to Analysis of Ultrasonic Signals through Melting Wax**
---**Sarah Lau**, David Moore, and Ciji Nelson, Sandia National Laboratories, Albuquerque, NM 87123

11:10 AM **Stress Dependence of the Hall Coefficient of a Nickel-Base Superally**
---**Daigo Kosaka**, Anatoli Frishman, and Norio Nakagawa, Iowa State University,Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Experimental Study the Acoustoelastic Lamb Wave in Thin Plates**
---**Ning Pei** and Leonard J. Bond, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3041

11:50 AM **The Influence of Ultrasonic Frequency on Stress Measurement Using Acoustoelasticity**
---**Zeynab Abbasi**[1] and Didem Ozevin[1], [1]University of Illinois at Chicago, Civil and Materials Engineering, 842 W. Taylor Street ERF 2095, Chicago, IL 60607

12:10 PM ***Lunch***

8:30 AM

Enhancing Pulsed Eddy Current for Inspection of P-3 Orion Lap-Joint Structures

---**D. M. Butt**[1], P. R. Underhill[2] and T. W. Krause[2], [1]Department of Chemistry and Chemical Engineering, Royal Military College of Canada, Kingston ON K7K 7B4, Canada;
[2]Department of Physics, Royal Military College of Canada, Kingston ON K7K 7B4, Canada

---During flight, aircraft are subjected to cyclic loading. In the Lockheed P-3 Orion airframe, this cyclic loading can lead to development of fatigue cracks at steel fastener locations in the top and second layer of aluminum wing skin lap-joints. An inspection method that is capable of detecting these cracks, without fastener removal, is desirable as this can minimize aircraft downtime, while subsequently reducing the risk of collateral damage. The ability to detect second layer cracks has been demonstrated using a Pulsed Eddy Current (PEC) probe design that utilizes the ferrous fastener as a flux conduit. This allows for deep penetration of flux into the lap-joint second layer and consequently, sensitivity to the presence of cracks. Differential pick-up coil pairs are used to sense eddy current response in the presence of a crack. The differential signal, obtained from pick-up coils on opposing sides of the fastener, is analyzed using a modified Principal Components Analysis (mPCA). This is followed by a cluster analysis of the resulting mPCA scores to separate fastener locations with cracks from those without. Probe design features, data acquisition system parameters and signal post-processing can each have a strong impact on crack detection. Physical probe and signal analysis processes, used to enhance the PEC system for detection of cracks in P-3 Orion lap-joint structures, are presented.

8:50 AM

A Model-Based Change Index for Damage Mapping

---**V John Mathews**, University of Utah, Department of Electrical & Computer Engineering, Salt Lake City, UT 84112-9206

---In structural health monitoring (SHM) algorithms employing baseline signals, computation of a change/anomaly/damage index for each actuator-sensor pair is often the first step toward characterization of damage in the structure. The change index associated with an actuator- sensor pair is a non-negative measure of the differences between a baseline signal and a test signal acquired subsequently at a different time associated with the actuator-sensor pair. One of the most commonly employed change indices is the signal difference coefficient (SDC) which is given by one minus the absolute value of the correlation coefficient between the baseline signal and the test signal. While the SDC has many attractive properties, the variability of this measure increases with the distance between the actuator and the sensor located on the structure. Consequently, many damage mapping algorithms utilize only SDC values associated with actuator-sensor pairs corresponding to relatively short distances between the actuator and the sensor. This paper presents a change index that is not sensitive to variations in the distance between the actuators and sensors, and therefore represents a more accurate characterization of the differences between the baseline and test signals [1]. The change index is obtained as a nonlinear transformation of the SDC between the outputs of a propagation model estimated from the baseline sensor signals and another propagation model estimated from the test sensor signals for the same excitation signal. In addition to the robustness to variations in the path length between actuators and sensors, this change index exhibits several attractive properties useful for SHM applications. For example, it is shown experimentally that the change index increases with the length of the wave propagation path that overlaps damage areas. Similarly, the change index is also sensitive to the distance of the wave propagation path between the actuator and the sensor to the damage area. Furthermore, it is possible to use different excitation signals to calculate the change index than those used to estimate the propagation models. This property allows calculation of multiple change indices using input signals that may be sensitive to specific damage features without actually exciting the signal separately using each input signal. This paper will demonstrate the properties of the new change index using experimental data obtained from a composite structure and contain results of tomographic damage mapping [2] of the structure employing the new change index.---Part of this work was performed under a contract from the Boeing Company. This work was also supported in part by Air Force Office of Scientific Research through Award No. FA99501210291.

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1. V. J. Mathews, "Model-based dissimilarity indices for health monitoring systems," *US Patent No. 7,720,626*, 2010.
2. V. J. Mathews, "Damage mapping in structural health monitoring using a multi-grid architecture," *Proc. Review of Progress in Quantitative Nondestructive Evaluation*, Boise, ID, July 20-25, 2014.

9:10 AM

Evaluation and Reconstruction of Wave Features in Wind-Driven Water Film Flow Using Ultrasonic Pulse-Echo Technique

---**Yang Liu**[1], Leonard J. Bond[1,2], and Hui Hu[1], [1]Iowa State University, Department of Aerospace Engineering, 2271 Howe Hall, Room 1200, Ames, IA 50011; [2]Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, 151 ASC II, Ames, IA 50011

---Aircraft operating in situations with high liquid water content and large droplets size at temperatures just below the freezing point face the risk of glaze icing. In glaze ice growth, the impinged droplets won't freeze immediately on impact, but will form into films and run back over aircraft surfaces or existing ice surfaces before freezing downstream. The run-back behaviors of the surface water will redistribute the impinging water mass and disturb the local flow field, and hence, affect the morphology of ice accretion and the rate of formation. Understanding conditions that lead to severe glaze icing events is important and challenging. In this study, An Ultrasonic Pulse-Echo (UPE) technique was used to provide time-resolved multi-point thickness measurements of surface water flows driven by boundary layer airflow. The water runback behavior on a test plate is evaluated by measuring the thickness variation of the water film along the surface using UPE technique under various wind speed and flow rate conditions. 3-D wave structures in both time and space domains are reconstructed based on the multi-point thickness measurements. The results indicate that the wind speed significantly affects the air-water interfacial wave pattern. At a low wind speed level, a quasi-sinusoidal wave motion dominates the water film flow, in which the wave frequency and wave length can be altered by the water flow rate. The wave motion develops to multiple discrete pulse patterns as wind speed increases.

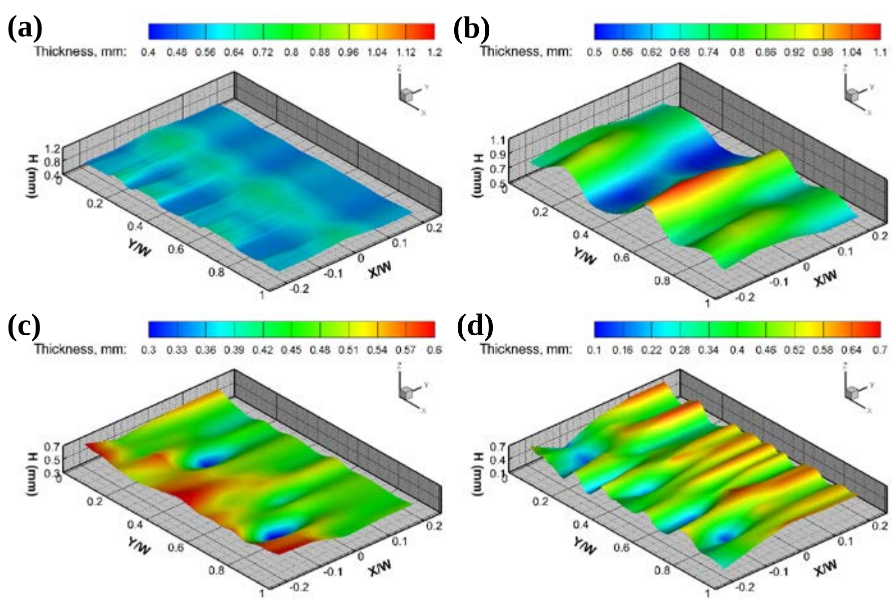


Figure 1. Reconstruction of wave features in wind-driven water film flow at V_∞ = 15m/s

9:30 AM

Ensemble of Classifiers for Confidence-Rated Classification of NDE Signal

---**Portia Banerjee**, Seyed Safdarnejad, Lalita Udpa, and Satish Udpa, Michigan State University, Non Destructive Evaluation Laboratory, Department of Electrical and Computer Engineering, East Lansing, MI 48824

---Ensemble of classifiers aims at improving the classifier accuracy by combining results from multiple 'weak' hypotheses into a single 'strong' classifier through weighted majority voting. Improved versions of ensemble of classifiers generate self-rated confidence scores which estimate the reliability of each of its prediction and boost the classifier using these confidence-rated predictions. However, such a confidence metric is based only on the rate of correct classification. In existing works, although ensemble of classifiers has been widely used in computational intelligence, the effect of all factors of unreliability on the confidence of classification is highly overlooked. With relevance to NDE, classification results are affected by inherent ambiguity of classes, non-discriminative features, inadequate training samples and noise due to measurement. From Bayesian point of view, posterior probability is considered as a confidence measure. Posterior probability of occurrence of an event is representative of inter-class similarities and intra-class distance and thus, may be used as a measure of inherent ambiguity of classes and discriminative quality of features. However, estimation of posterior probability is itself affected by quantity of available training samples. A framework which incorporates these two major sources of classification error in a single confidence measure would generate a more comprehensive estimate of reliability. In this paper, we extend the existing ensemble classification by maximizing confidence of every classification decision in addition to minimizing the classification error. Initial results of the approach on data from ultrasonic weld inspection will be presented.

9:50 AM

A Robust Multi-frequency Mixing Algorithm for Suppression of Rivet Signal in GMR Inspection of Riveted Structures

---**S. Safdarnejad**, O. Karpenko, L. Udpa, and S. S. Udpa, Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48824

---Eddy current probes with Giant Magnetoresistive (GMR) elements have recently been utilized as efficient tool for inspection of riveted structures. However, rivet indication generally predominates the contribution from subsurface defects, making defect detection a difficult task. Given that eddy current depth of penetration is different at different frequencies, multi-frequency mixing aims to suppress the indication of rivet, while retaining the defect indication, by fusing the measurements at two different frequency. For this purpose, the high frequency measurement, which is mainly due to rivet structure, is transformed and subtracted from the low frequency measurement, containing both rivet and probable defect contributions. Estimation of transformation parameters for mixing is performed by finding the parameters that minimize the rivet indication on the mixed signal. Baseline measurements from a defect-free rivet is used for parameter estimation. Initial experimental results demonstrate that multi-frequency mixing substantially enhances defect indications. Furthermore, we propose a robust parameter estimation algorithm which does not depend on baseline signal for parameter estimation, and instead, robustly estimates the parameters from the inspection data under study. The proposed algorithm is based on the random sample consensus (RANSAC) algorithm, in which parameters of a mathematical model are estimated from a set of observed data which contains outliers. This procedure consists of multiple trials in each of which we draw a spatial subsample of measurements, and estimate the parameters for each sample subset. If enough iterations are tried, and in one of the iterations the subsample does not include measurements from defect indication region, the estimation parameters will suppress the rivet indication effectively. Thus, in each iteration, we evaluate the mixing performance against an objective function to find the best subsample for parameter estimation. Initial results demonstrate that the proposed algorithm is as effective as baseline-based mixing algorithm.---This material is based upon work supported by the AFRL under contract No. FA8650-10-D-5201, Task Order 014.

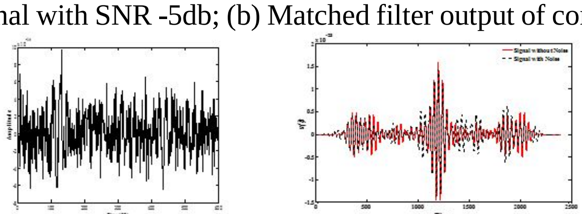
10:30 AM

Modeling of Ultrasonic Guided Waves for Circular Cylindrical Structures Using Finite Element Approach and Selection of Noise Filtering Technique

---**Ambuj Sharma**[1], Mayank Nirbhay[2], and Amit Tyagi[1]; [1]Mechanical Engineering Department, IIT (BHU) Varanasi-221005, India; [2]Deparatment of Mechanical Engineering, GBU, Greater Noida-201308, India

---Shell type structure like thin walled tubes and hollow cylinders are very crucial components of oil, gas and chemical based industries. The successfully detection of cracks and flaws in pipes is very important issue. This requires analysis of three-dimensional ultrasonic guided wave propagation and reflection in hollow cylinders. Lamb waves have great potential for detection of flaws of long pipe works. However, the major limitations of Lamb wave techniques are due to multiple propagation modes with different group velocity in single frequency. So recognition of the modes is not easy [1, 2]. The objective of this study is to establish the effectiveness of finite element method to model guided wave propagation problems for cylindrical shell structures and the multi-feature technique of signal analysis particularly in enormously noisy signal. The interaction of lamb waves with circumferential defects is examined by using this technique. In this paper, Lamb wave generation and the interaction law with the defects in hollow cylinder is studied through associating ultrasonic cylindrical guided wave theory with finite element approach. Various numerical experiments are conducted by using ABAQUS, FEA based commercial package. Longitudinal L (0, 2) mode and torsional T (0, 1) mode of the propagation are analysed in the hollow cylinder. The maximum and minimum reflection coefficient values at varying axial extent are distinguished and can be utilized for the decision of defect sizing. Various signal processing and denoising techniques are developed to extract signals from measured noisy signal. A large number of filtering techniques are based on wavelet transform (WT) [3, 4]. A detail study of wavelet applications in the structural health monitoring and lamb wave based crack detection methods are performed by Taha *et al.* [5]. In this paper, capabilities of wavelet and matched filtering techniques are compared. To provide greater insight for performance evaluation of filtering techniques, processing of acquired ultrasonic signals with a low signal to noise ratio (SNR) problem is addressed. In order to evaluate the performance of filtering techniques, matched filtering technique and wavelet based filtering are tested. Results show that when very severely contaminated Lamb wave signals are processed, as shown in Fig.1(a), matched filter is able to detect the Lamb wave signal. This is illustrated by showing the signal with noise and without noise in Fig. 1(b), therefore establishing its usefulness.

Fig. 1. (a) Contaminated signal with SNR -5db; (b) Matched filter output of contaminated signal SNR -5db.



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10:50 AM

Application of Temporal Moments and Other Signal Processing Algorithms to Analysis of Ultrasonic Signals through Melting Wax

---Sarah Lau, David Moore, and Ciji Nelson, Sandia National Laboratories, Albuquerque, NM 87123

---Ultrasonic analysis is being explored as a way to capture events during material melt tests. Events include temperature changes in the material, phase transition of the material, surface flows and reformations, and void filling as the material melts. Melt tests with wax are used to evaluate the usefulness of different signal processing algorithms in capturing event data. Two algorithm paths are being pursued. The first checks the magnitude squared coherence and correlation between two ultrasonic signals and then estimates a time delay from the first signal to the second [1]. This is only appropriate when the changes from one ultrasonic signal to the next can be represented by a linear relationship, which is not always the case. The second algorithm tracks changes in the temporal moments of a signal over a full test [2]. This method does not require that the changes in the signal be represented by a linear relationship, but attaching changes in the temporal moments to physical events can be difficult. This paper will apply the two algorithm paths to experimental data from a wax melt test and explore different ways to display the ultrasonic results.---Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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11:10 AM

Stress Dependence of the Hall Coefficient of a Nickel-Base Superalloy

---**Daigo Kosaka**, Anatoli Frishman, and Norio Nakagawa, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50011

---This work is motivated by the desire to develop a nondestructive method of characterizing the near-surface protective residual stress in metals, by way of Hall coefficient measurements. The method is based on the assumption that Hall coefficient is inversely proportional to the charge carrier density, which, in turn, is inversely proportional to the stress. Thus, it is expected that Hall coefficient is proportional to the stress. This relationship is simpler than that of the electrical conductivity, which has more complex dependencies on the charge carrier characteristics, not only on its density, but also on the transport characteristics such as the mean- free path and Fermi momentum. Thanks to the simpler underlying physics, it is anticipated that Hall Effect measurements can show more straightforward stress dependency than the conductivity-based measurements such as eddy current. The present study is fundamental in nature, and about the basic property measurements of the Hall coefficient and its stress dependency. Our focus is on nickel-base superalloy Inconel® 718, where the challenge is to measure small stress-induced changes of the Hall coefficient, which itself is small. The challenge has been met by the use of an AC bias current and AC magnetic field. The presentation will cover the details of the experimental setups and measurement procedures, such as shown in Fig. 1, explaining how the Hall Effect measurements were conducted under applied tensile loads to a sample. Figure 2 shows example data plots, i.e. the measured Hall coefficient plotted against the applied tensile strain under 3 repeated stress cycles. The data indeed show that the Hall coefficient of our sample exhibits linear stress dependency, from which the numerical data of the Hall coefficient and its stress gradient will be extracted in the presentation, for Inconel 718. Additional studies on measurement sensitivities on the sample temperature, the magnitude and frequency of bias current, and magnitude and frequency of magnetic field, will be also discussed. ---This work was supported in part by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

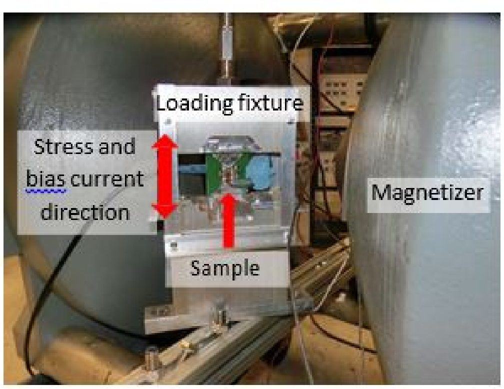

Figure 1. Sample and loading fixture.

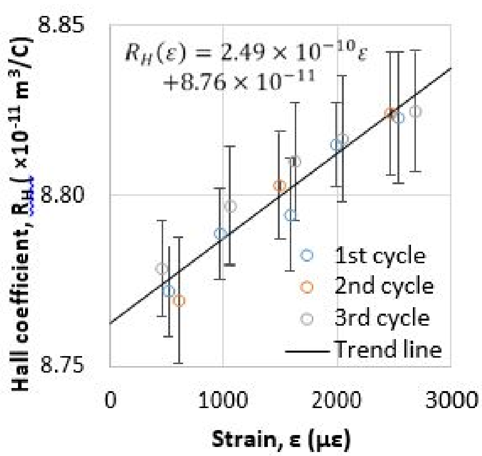

Figure 2. Stress dependence of Hall coefficient of Inconel 718 under three repeated stress cycles.

11:30 AM

Experimental Study the Acoustoelastic Lamb Wave in Thin Plates

---**Ning Pei** and Leonard J. Bond, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3041
---Fabrication processes, such as, welding, forging, and rolling can induce residual stress in metals that will impact product performance and phenomena such as cracking and corrosion. To better manage residual stress tools are needed to map their distribution. For ultrasonic aspect, the critically refracted ultrasonic longitudinal (LCR) wave method [1-2] and shear wave birefringence are the two main methods for residual stress detection [3]. However, there is a much more limited literature that discusses acoustoelastic phenomena for Lamb waves in thin plate [4-5]. In this paper the relationships between velocity and frequency are studied experimentally [6] for different modes, under various stress loadings. The result shows that the sensitivity of different modes various a lot, the A1 mode is the most sensitivity: if the force is added to 100 MPa, the change stress of A1 mode can be as large to 80 m/s. That's to say A1 mode is a good choice for residual stress detection.--- This work was supported by China Scholarship Council (CSC).

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11:50 AM

The Influence of Ultrasonic Frequency on Stress Measurement Using Acoustoelasticity

---**Zeynab Abbasi**[1] and Didem Ozevin[1], [1]University of Illinois at Chicago, Civil and Materials Engineering, 842 W. Taylor Street, ERF 2095, Chicago, IL 60607

---The fundamental theory of nonlinear ultrasonics is used in the quantification of the stress states in a complex loaded structural element. Acoustoelasticity which uses nonlinear ultrasonics is the stress dependence of ultrasonic wave velocity in a stressed media. In order to measure the stress a perturbation signal is introduced and the frequency shift is measured at the receiving location, however the correlation between the stress and ultrasonic signal is weak therefore precise measurement is required in order to achieve accurate results. In this paper, the effect of sensor frequency on stress measurement is investigated. Rayleigh wave penetration depth which is approximately one wavelength decreases as the selected frequency increases. In this study three frequencies (0.5, 1 and 3 MHz) are considered, and their effects on the acoustoelasticity coefficient are numerically examined. It is observed that as the ultrasonic frequency decreases, the acoustoelastic coefficient increases; therefore the resolution needed to detect low stress levels increases. Additionally, errors due to measuring methodology, equipment, coupling agents (oil and ultrasonic gel), different frequencies and various plate surface roughness values are experimentally measured. By identifying the random and systematic errors the measurement uncertainty is quantified and the minimum detectable stress level using coupled ultrasonic sensors is determined.

Session 21

SESSION 21
6th EAW
Lakeshore A

HUMAN AND ORGANIZATIONAL FACTORS
Ralf Holstein and Greg Selby, Co-Chairpersons

8:30 AM **Safety and Organizational Culture in NDT Matter**
---Babette Fahlbruch[1] and **Marija Bertovic**[2], [1]TUV NORD Systems, Zimmerstr. 23, 10969 Berlin; [2]DGZfP Ausbildung and Training GmbH

8:50 AM **Basic Considerations about Reliability in Testing Railway Axles**
---**Ralf Holstein**[1], Marija Bertovic[1], and Christina Müller[2], [1]DGZfP Ausbildung und Training, GmbH, Berlin, Germany; [2]BAM Federal Institute for Materials Research and Testing, Berlin, Germany

9:10 AM **Inspection Procedure in the Context of the Usability Framework – Human Factors Approach**
---**Marija Bertovic**[1] and Ulf Ronneteg[2], [1]DGZfP Ausbildung und Training GmbH; Berlin, [2]SKB, Swedish Nuclear Fuel and Waste Management Co; Oskarshamn, Sweden

9:30 AM **Predicting Inspector Probability of Detection Using Qualification Test Pass Rates**
---**Stephen Cumblidge**, US Nuclear Regulatory Commission, Mail Stop OWFN/9 H6, Washington, DC 20555-0001

9:50 AM **WITHDRAWN - Reliability Assessment of Manual and Automated Eddy Current Techniques in the Inspection of Martensitic Stainless Steel Components**
---**Hamid Habibzadeah Boukani**[1], Ehsan Mohseni[1], Demartonne Ramos Franca[1], and Martin Viens[1], [1]Départment de genie mécanique, L'École de technologie Supérieure, Montréal, Québec, Canada

10:10 AM ***Break***

10:30 AM **Influencing Factors on the Inspection Performance of Wheel Axle Sets Under Training Conditions**
---**Thomas Heckel**, et al., BAM Bundesanstalt fur Materialforschung und -prufung, FG 8.4, Berlin 12205

OPEN SPACE TECHNOLOGY WORKSHOP
Ralf Holstein and Greg Selby, Co-Chairpersons

10:50 AM **Introduction to the Open Conception, Ralf Holstein**

11:10 AM **Results from 2013**

11:30 AM **Structuring of Topic Fields According to the "Wall of Ideas"**
Preliminary Proposal for Topic Fields:
Group 1: New Methods
David Forsyth and Daniel Kanzler

Group 2: Human Factors
Marija Bertovic and Ralf Holstein

Group 3: SHM
Eric Lindgren

Group 4: Industrial Applications
Lloyd Schafer

Group 5: Integrated Solutions
Ulf Ronneteg and Stephen Cumblidge

12:10 PM ***Lunch***

8:30 AM

Safety and Organizational Culture in NDT Matter

---**Babette Fahlbruch**[1] and Marija Bertovic[2], [1]TUV NORD Systems, Zimmerstr. 23, 10969 Berlin; [2]DGZfP Ausbildung and Training GmbH

---The process of NDT can be affected not only by the inspector, organizational and inter-organizational factors may promote the system to fail. Time or production pressure, inappropriate procedures or leadership as well as conflicting goals can lead inspectors to perform their inspection task not in the planned way. But does organizational culture as well have an influence? Are there common beliefs how to perform tasks, how to use procedures, how to supervise employees? In the 80ies and 90ies of the last century, international comparisons of production efficiency in Western and Japanese companies, have indicated that culture may be an important factor in the then presumed superior Japanese industrial performance (Womack, Jones & Roos, 1990). Later managers, politicians, training institutions and consulting bodies have heartily embraced the term and have made the promotion of culture in its many-faceted nature to become a self-propelling concern. Especially in high hazard industries safety culture as part of the organizational culture has become a catchword. As a result from the shock of the Chernobyl catastrophe the International Safety Advisory Group (INSAG) of the International Atomic Energy Agency (IAEA) tried to comprehend the Chernobyl events. The term safety culture was used to explain the unexplainable (INSAG, 1991): "Safety culture is that assembly of characteristics and attitudes in organization and individuals that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance". Features and attitudes of organizations and of individuals are used to define safety culture here. Although these characteristics are certainly important, the definition remains too much in the mental-cognitive domain. There exists lots of research evidence in social psychology that attitudes and action do not always correlate highly. Therefore, already in 1991, the original INSAG definition was criticized because it leaves out what is of primordial importance: safety related behavior (Wilpert, 1991). In spite of its wide diffusion and use, the term safety culture is still vague in its understanding and theoretical underpinnings. A growing consensus emerges that safety culture ought to be conceived as a holistic and integrating concept. The paper will present important conceptualizations as well as approaches for assessment.

8:50 AM

Basic considerations about reliability in testing railway axles:

Ralf HOLSTEIN [1]Christina MÜLLER [2, 1] DGZfP Ausbildung und Training GmbH. Berlin, Germany, [2] BAM Federal Institute for Materials Research and Testing, Berlin, Germany

Non-destructive testing is an important tool to guarantee the safety of railway traffic. The infrastructure with tracks, switches and sleepers is regularly tested, the locomotives and wagons with their wheels, bogies and axles as well.

A draft standard about "Requirements for non-destructive testing on running gear in railway maintenance" states about the framework: "A sound Maintenance Plan for Rolling Stock helps guarantee safe operation of railway vehicles at the right cost. It deals with wear, unintended damage or malfunction, and takes into account the vehicles usage and the track conditions. In this context, NDT are used to search for running gear faults and failures."

This statement includes the words "plan" and "costs" and indicates that the importance of organizational factors is well known in railway maintenance.

Many years of experience and some critical events lead in Germany to a good practice in testing the railway components. This practice combines an intensive training of the NDT-personnel including sufficient time for practical exercises with organizational measures.

Through the example of manual UT-testing of hollow axles it will be shown, how training and organizational measures influence the reliability of such testing.

9:10 AM

Inspection Procedure in the Context of the Usability Framework - Human Factors Approach

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---NDT inspection procedures and instructions are, without question, some of the most important tools in the everyday life of an NDT inspector. Experience and research have shown that, despite being written according to requirements and by certified personnel, NDT procedures and instructions are not always used as foreseen and may need to be optimized. In order for it to fulfill its purpose and guide the inspector towards a successful completion of the inspection task, the procedure needs not only to contain all the relevant information, but also communicate the information in a way which allows the operator to conduct the task effectively and efficiently. Four studies were conducted to develop a new format of a selected procedure, i.e. the NDT instruction for the ultrasonic inspection of the cast iron insert (part of a canister used for the permanent disposal of spent nuclear fuel in Sweden). This was achieved by involving the users in the development of the instruction (*user-centered design*): by following their eye movements during a data evaluation task whilst using the instruction, and by interviews and group discussions. Accompanied by a review from a human factors' perspective and the suggestions from relevant literature (e.g. McGrath, 2008), a new instruction format was created. This new instruction was then experimentally investigated for the understanding of the content and for its usability. By comparing the old instruction format to the newly developed one, the results showed that appropriately highlighting warnings, exceptions, or reminders and placing them at the correct position assures that they will be read and identified with ease rather than overlooked. The presentation of the information in a stepwise manner, with one action per step, allows the user to more easily follow the steps that must be carried out to save time and effort.
Both the instruction content and instruction format play an important role in producing reliable instructions. The instruction content aids in the understanding of the task and in its subsequent correct execution. The instruction format determines the efficiency and frequency of the instruction's use. The review of the instruction should be carried out through action, not solely through reading, as some problems can only be identified when an instruction is used, especially in complex cases.

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1. McGrath, B., 2008. Programme for the Assessment of NDT in Industry, PANI 3 [Report No. RR617], Health and Safety Executive.

9:30 AM

Predicting Inspector Probability of Detection Using Qualification Test Pass Rates

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The United States Nuclear Regulatory Commission (NRC) staff has been working since the 1970's to ensure that nondestructive testing performed on nuclear power plants in the United States will provide reasonable assurance of structural integrity of the nuclear power plant components. One tool used by the NRC has been the development and implementation of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section XI Appendix VIII (Appendix VIII) blind testing requirements for ultrasonic procedures, equipment, and personnel. Over the past several years questions have been raised by some in industry and the NRC over the relatively low pass rates for the Appendix VIII qualification testing. The NRC staff has applied statistical tools and simulations to determine the expected probability of detection (POD) for ultrasonic examinations under ideal conditions based on the pass rates for the Appendix VIII qualification tests for the ultrasonic testing personnel. This work was primarily performed to answer three questions. First, given a test design and pass rate, what is the expected overall POD for inspectors? Second, can we calculate the probability of detection for flaws of different sizes using this information? Finally, if a previously qualified inspector fails a requalification test, does this call previous inspections conducted by this inspector into question? The calculations have shown that one can expect good performance (POD ≈ 80%) from inspectors who have passed appendix VIII testing in a laboratory-like environment, there is insufficient information to determine the POD for different flaw sizes, and the similar failure rate for the requalification tests suggest that the inspectors have maintained a similar POD as when they originally passed the qualification test.

Additionally, while these calculations showed that the PODs for the ultrasonic inspections appear to be good under laboratory conditions, the field inspections are conducted in a very different environment. The NRC staff has initiated a project to systematically analyze the human factors differences between qualification testing and field examinations. This work will be used to evaluate and prioritize any possible human factors issues that may degrade performance in the field.

9:50 AM

Reliability Assessment of Manual and Automated Eddy Current Techniques in the Inspection of Martensitic Stainless Steel Components

---**Hamid Habibzadeh Boukani**[1], Ehsan Mohseni[1], Demartonne Ramos Franca[1], Martin Viens[1]
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---Sizing and positioning of fatigue cracks on critical components are of high importance. Among various non-destructive testing (NDT) methods, Eddy current (EC) testing is the best suited method for this purpose. Reflection differential split-D EC probes are very sensitive to surface breakings since the signal to noise ratio for these probes are fairly high considering their differential configuration. This makes them the top choice for inspecting surface fatigue cracks. Life estimation models have several inputs one of which is the dimensions of existing flaws in the structure; this input is mainly determined by means of NDT methods. Therefore, accurate sizing and positioning of flaws remarkably affect the outcome of these models. This accuracy mainly depends on the inspection technique and parameters which should be defined at their most optimized levels. In order to evaluate and quantify the reliability of NDT methods, probability of detection (POD) is used as a general metric. The outcome of POD curves determines which crack size can be fed into the models with high degree of certainty. Some former studies investigated the POD of bolt hole discontinuities in aluminum alloys using the specific differential probe designed for this purpose [1, 2]. In this research, the reliability of manual and automated eddy current testing methods, using split-D probe, are compared in terms of their POD. Furthermore, the impact of frequency change on the POD curves and the effect of automation on the noise characteristics are evaluated. In addition, the sensitivity of reliability to frequency sweep is investigated for both manual and automated techniques. Samples containing fatigue induced cracks with specified length and depth were used to create POD curves in this research. For the manual inspection, POD curves were generated by the data obtained from different inspectors. On the other hand, an encoded scanning system was used to scan the samples in the automatic inspections. The dispersion in the received signals was due to the variability of crack orientation and characteristics, probe tilt and lift-off, inspectors, and working shifts. The inspections were performed at three working frequencies and for each technique the sensitivity of reliability to frequency variation as well as noise characteristics were investigated and compared. This research is a part of a large scale project which is aimed at finding the best eddy current inspection parameters and techniques for martensitic stainless components of aeronautic industry.

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10:30 AM

Influencing factors on the inspection performance of wheel axle sets under training conditions

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The training of personnel for the inspection of wheel set axles for the railway sector is performed at DGZfP training centre Wittenberge, Germany. Basic training for manual ultrasonic inspection on hollow axles is performed at course U1-M1. A follow up training at course U1-M2 supplements the skills and knowledge necessary for mechanized inspection. These training courses have now been offered for more than ten years using a fixed training plan. This is an ideal basis for an analysis using statistical methods. For the evaluation of the influencing factors on the reliability of the inspection of hollow axles DGZfP and BAM started a project with the goal to optimize the training programme. A round robbing test based on the available axles and probes at DGZfP training centre Wittenberge has been established and a database for the acquisition of the testing results has been built at BAM. On selected test pieces detailed investigations using advanced inspection methods have been carried out to characterize the flaws in detail. On each test piece a reference measurement has been performed for the database reference positioning, orientation type and size for each flaw. Probability of detection of the individual flaws has been calculated based on statistical analysis of the echo height amplitudes and the positions reported for the flaws. This contribution reports the actual status and an overview about this project. First evaluation results of this ongoing project will be presented.

Session 22

SESSION 22

ULTRASONIC ARRAYS II

Bob Addison and Paul Wilcox, Co-Chairpersons

Nicollet D1

1:30 PM **Optimization of Element Length in Linear Ultrasonic Arrays for Improved Detectability of Defects**
---**T. S. Barber**[1, 2], P. D. Wilcox[1], and A. D. Nixon[2]; [1]University of Bristol, Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom; [2]BAE Systems Submarines, Materials Technology, Barrow-in-Furness, Cumbria, LA14 1AF, United Kingdom

1:50 PM **Rapid Lamb Wave-Based Subwavelength Damage Imaging Using the DORT-MUSIC Technique**
---**Jiaze He**[1,2] and Fuh-Gwo Yuan[1,2], [1]Center for Integrated Structural Health Management, National Institute of Aerospace, Hampton, VA 23666; [2]Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695

2:10 PM **Crack Length Measurements by Subharmonic Phased Array for Crack Evaluation with Surface Acoustic Wave with Water Immersion**
---**Yoshikazu Ohara**, Akihiro Ouchi, Juri Saito, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, 980-8579, Japan

2:30 PM **Frequency Domain Ultrasound Imaging for Frequency Selective Nonlinear Sub-Harmonic Phased Array Imaging**
---**Choon-Su Park**, Jun-woo Kim, Seunghyun Cho, and Dae-Cheol Seo, Korea Research Institute of Standards and Science, Yuseong-gu, Daejeon, South Korea

2:50 PM **OPEN**

3:10 PM ***Break***

NON-LINEAR

Christopher Kube and Daniel Barnard, Chairpersons

3:30 PM **Measurement of Nonlinearity Parameter (B) of Water Using Commercial Immersion Transducer**
---Daniel J. Barnard and **Sunil Kishore Chakrapani**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50011

3:50 PM **Binding Conditions for Nonlinear Ultrasonic Modulation Generated by a Localized Fatigue Crack**
---Hyung Jin Lim, **Hoon Sohn**, and Yangtak Kim, Korea Advanced Institute of Science and Technology (KAIST), Department of Civil and Environmental Engineering, 291 Daehak-Ro, Guseong-Dong, Yuseong-Gu, Daejeon, 305-701, Republic of Korea (South Korea)

4:10 PM **Time-Domain Analysis of Resonant Acoustic Nonlinearity Arising from Cracks in Multilayer Ceramic Capacitors**
---**Ward L. Johnson**, Sudook A. Kim, and Grady S. White, National Institute of Standards and Technology, 325 Broadway St., MS 647, Boulder, CO 80305; Jaemi Herzberger, University of Maryland, Department of Mechanical Engineering, College Park, MD 20742

4:30 PM **A Novel and Practical Approach for Determination of the Acoustic Nonlinearity Parameter Using a Pulse-Echo Method**
---**Hyunjo Jeong**[1], Shuzeng Zhang[2], Sungjong Cho[1], Xiongbing Li[2], and Dan Barnard[3], [1]Division of Mechanical and Automotive Engineering, Wonkwang University, Iksan, Jeonbuk 570-749, Republic of Korea; [2]School of Traffic and Transportation Engineering, Central South University, Changsha, Hunan, 410075, China; [3]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011

4:50 PM **Experimental Comparison of Nonlinear Parameters Obtained from Absolute Measurement and Relative Measurement**
---**Jongbeom Kim**[1], Dong-Gi Song[1], Younho Cho[2], Chung-Seok Kim[3], and Kyung-Young Jhang[4],[1]Department of Mechanical Convergence Engineering, Hanyang University, Seoul, Republic of Korea, 133-791; [2]School of Mechanical Engineering, Pusan National University, Busan, South Korea, 609-735; [3]Department of Metallurgy and Materials Engineering, Chosun University, Gwangju, Republic of Korea, 501-759; [4]School of Mechanical Engineering, Hanyang University, Seoul, Republic of Korea, 133-791

1:30 PM

Optimization of Element Length in Linear Ultrasonic Arrays for Improved Detectability of Defects

---**T. S. Barber**[1, 2], P. D. Wilcox[1], and A. D. Nixon[2]; [1]University of Bristol, Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom; [2]BAE Systems Submarines, Materials Technology, Barrow-in-Furness, Cumbria, LA14 1AF, United Kingdom

---Linear ultrasonic arrays (phased arrays) are now a frequently used tool in industry and form a critical part of NDE inspection requirements of a variety of components and materials. Linear arrays can be defined by four main parameters namely, centre frequency, number of elements as well as the element width and length. The first three are generally considered to be the most important and much work has concentrated on using 2D array models to optimise these parameters to suppress grating lobes, improve resolution and maximise inspection coverage but less is known about influence of the length of the elements perpendicular to the imaging plane. This parameter is often arbitrarily chosen when designing an array and requires a 3D array data model to understand its effects on imaging performance fully. This work presents a study into the optimisation of element length for the improved detectability of known simple flaws in a material using linear ultrasonic arrays. Building on previous work a 3D ultrasonic data model described and is used to understand the relationship between the defect signal, single scattering noise level and consequently the Signal to Noise Ratio (SNR) as a function of element length, flaw position and frequency. The model results are compared to experimental work and a series of guidelines are then outlined to help towards defining the optimal length for a particular inspection challenge. The work is then applied to a practical problem of the immersion inspection of small-bore thin-walled pipework. This work is supported by the UK Engineering and Physical Sciences Research Council through the UK Research Centre in NDE (RCNDE).

1:50 PM

Rapid Lamb Wave-Based Subwavelength Damage Imaging Using the DORT-MUSIC Technique

---**Jiaze He**[1,2] and Fuh-Gwo Yuan[1,2], [1]National Institute of Aerospace, Center for Integrated Structural Health Management, Hampton, VA 23666; [2]North Carolina State University, Department of Mechanical and Aerospace Engineering, Raleigh, NC 27695

---A Lamb wave-based, subwavelength imaging algorithm is developed for damage imaging in large-scale, plate-like structures based on a decomposition of the time-reversal operator (DORT) method combined with the multiple signal classification (MUSIC) algorithm. In this study, a rapid non-contact scanning system was proposed to image an aluminum plate using a piezoelectric linear array for actuation and a laser Doppler vibrometer (LDV) line-scan for sensing. The physics of wave propagation, reflection, and scattering that underlies the response matrix ***K*** in the DORT method is mathematically formulated in the context of guided waves. Singular value decomposition (SVD) is then employed to decompose the experimentally measured response matrix into three matrices, detailing the incident wave propagation from the linear actuator array, reflection from the damage, and followed by scattering waves toward the linear sensing array for each site of small damage. The SVD and MUSIC-based imaging condition enable quantifying the damage severity by a 'reflectivity' parameter and super-resolution imaging. With the flexibility of this scanning system, a considerably large area can be imaged using lower frequency Lamb waves with limited line-scans. The experimental results showed that the hardware system with a signal processing tool such as the DORT-MUSIC (TR-MUSIC) imaging technique can provide rapid, highly accurate imaging results as well as damage quantification with unknown material properties.

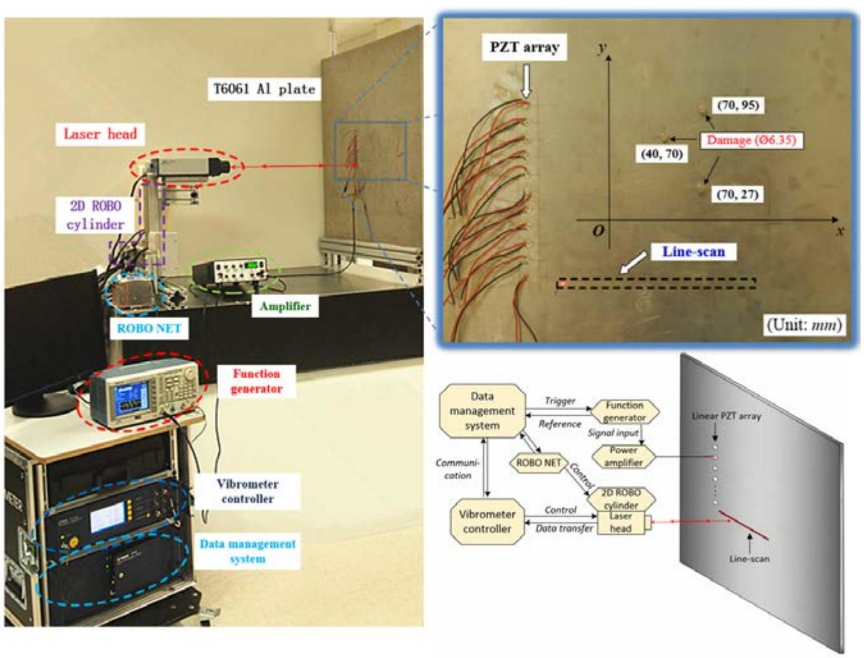

Figure 1. Experimental setup for the hybrid PZT/LDV scanning system for subwavelength imaging.

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Crack Length Measurements by Subharmonic Phased Array for Crack Evaluation with Surface Acoustic Wave with Water Immersion

---**Yoshikazu Ohara**, Akihiro Ouchi, Juri Saito, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, 980-8579, Japan

---For the measurement of crack length, ultrasonic testing from the anti-crack opening side does not have a sufficient sensitivity, since the edge part of a crack in the length direction is generally shallow. To solve this problem, we extended a closed crack imaging method, subharmonic phased array for crack evaluation using bulk waves (Bulk SPACE) [1] in terms of using surface acoustic waves. In the first implementation, an acrylic wedge with a critical angle of Rayleigh wave was used to excite SAW via mode conversion by an array transducer. It was named contact-type SAW SPACE, and its fundamental performance was demonstrated [2]. However, the resolution of the images obtained by the contact-type SAW SPACE is not so high, because the use of frequencies higher than 5 MHz is difficult because of the attenuation within the wedge and the leaky loss of the SAW to the wedge. In this study, to achieve higher resolution, we extended SAW SPACE to water immersion (Fig. 1). Here an array transducer is set at a critical angle of a Rayleigh wave in water. By exciting the array transducer according to the delay law formulated on the basis of Fermat's principle, SAW is focused on an arbitrary point. By irradiating focused SAW to cracks, linear and nonlinear scattering occur at the open and closed parts of a crack, respectively. After receiving the scattered waves and filtering them at fundamental and subharmonic frequencies, they are shift-summed to create fundamental array (FA) and subharmonic array (SA) images. First, SAW SPACE with water immersion was applied to a specimen with a hole. As a result, the hole was imaged with a higher resolution at a correct position. Subsequently, it was applied to closed crack specimens. One of the imaging results for closed stress corrosion crack (SCC) is shown in Fig. 2. The SCC was imaged with different distribution in the FA and SA images. Note that the crack length measured in SA images was larger than those in the FA image and optical observation of side surface. This shows that SAW SPACE is useful in accurately measuring closed-crack length and imaging the distribution of open and closed parts of cracks.

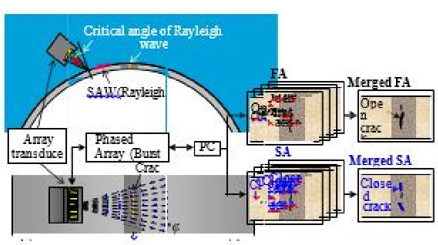

Figure 1. Schematics of SAW SPACE.

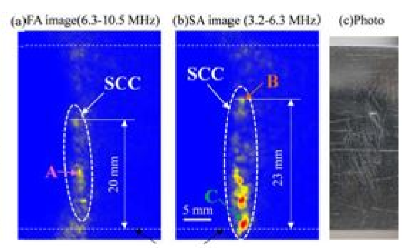

Figure 2. Imaging results of SCC.

References:

1. Y. Ohara, T. Mihara, R. Sasaki, T. Ogata, S. Yamamoto, Y. Kishimoto, and K. Yamanaka, "Imaging of Closed Cracks Using Nonlinear Response of Elastic Waves at Subharmonic Frequency," Appl. Phys. Lett., 103, 011902-1-3 (2007).
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2:30 PM

Frequency Domain Ultrasound Imaging for Frequency Selective Nonlinear Sub-Harmonic Phased Array Imaging

---**Choon-Su Park**, Jun-woo Kim, Seunghyun Cho, and Dae-Cheol Seo, Korea Research Institute of Standards and Science, Yuseong-gu, Daejeon, South Korea

---Nonlinear ultrasound inspection using sub-harmonic frequency has been proved to be a promising way to detect closed crack. In addition, sub-harmonic phased array (PA) was proposed to visualize where the closed crack is [1]. The sub-harmonic PA inherently has lower resolution than the fundamental frequency PA images, because sub-harmonic wavelength is longer than the fundamental one. The maximum peak of main-lobe represents a possible source location, and main-lobe beamwidth depends on the frequency of interest. The beamwidth becomes broad as frequency goes lower. The broad main-lobe often prevents from identifying where a source is. The frequency dependent characteristics could be well defined and observed by frequency domain beamforming. Furthermore, to improve spatial resolution of beamforming images, MUSIC (MUltiple SIgnal Classification) algorithm has been adopted [2]. Nonlinear ultrasound imaging with a phased array is examined with the MUSIC algorithm for sub-harmonic frequency components in frequency domain. In addition, some experimental results with CT specimens after cyclic load clearly show closed-crack location and open crack location with improved resolution.

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2. C.-S. Park, J.-W. Kim, S. Cho, and D.-C. Seo, "Resolution enhancement of subharmonic phased array using MUSIC algorithm," in 41st Annual Review of Progress in Quantitative Nondestructive evaluation, Center for Nondestructive Evaluation, (2014).

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Measurement of Nonlinearity Parameter (B) of Water Using Commercial Immersion Transducer

---Daniel J Barnard and **Sunil Kishore Chakrapani**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50011

---The determination of absolute nonlinearity parameter (b) for water using finite-amplitude method has been described here. Measurements were carried out using commercial immersion transducers, thus making this technique field adaptable. Calibration of immersion transducers is based on a simplified version of the calibration technique proposed by Dace et al. With corrections for diffraction and attenuation, the nonlinearity parameter calculated for water is in good agreement with literature, providing a validation for the methods developed. The current study is aimed at leading towards measuring the nonlinearity parameter of immersed solids using commercially available ultrasonic equipment. This work is supported by the Industry/University Cooperative Research Center members of the Center for Nondestructive Evaluation at Iowa State University.

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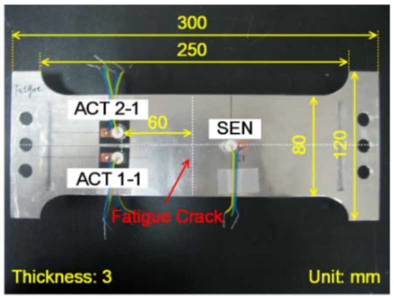
Binding Conditions for Nonlinear Ultrasonic Modulation Generated by a Localized Fatigue Crack

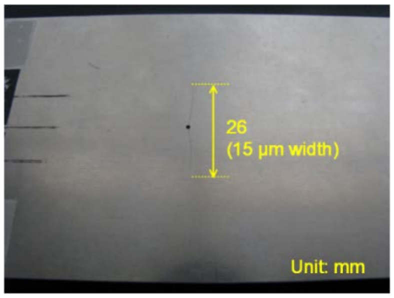
---Hyung Jin Lim, **Hoon Sohn** and Yongtak Kim, Korea Advanced Institute of Science and Technology (KAIST), Department of Civil and Environmental Engineering, 291 Daehak-Ro, Guseong-Dong, Yuseong-Gu, Daejeon, 305-701, Republic of Korea (South Korea)

---The binding conditions (BCs) for the nonlinear ultrasonic modulation, produced by a localized nonlinear source such as a fatigue crack, are theoretically formulated and experimentally validated. First, by assuming that propagating linear waves cause crack opening/closing and subsequently the fluctuation of Young's modulus, a theoretical model for a localized crack is derived [1-2]. Then, the BCs for the localized crack are formulated. For the experimental validation, an aluminum plate specimen is fabricated as shown in Fig. 1(a). A fatigue crack initiated from the hole at the center of the specimen as shown in Fig. 1(b). A pair of PZTs labeled as ACT 1-1 and 1-2 are collocated but placed on the opposite sides of the specimen, and another pair of ACT 2-1 and 2-2 are installed similarly for generation of selective symmetric and anti-symmetric modes. The response is measured at SEN. The input frequencies for the validation are determined considering the phase velocity dispersion curves and experimental mode shapes obtained by 3D Laser Doppler Vibrometer (LDV) scanning of the crack area. The BCs for localized crack nonlinearity are experimentally validated and compared with the BCs for distributed material nonlinearity [3]. Additionally, the effects of propagating waves and stationary vibration on the BCs are investigated.

---This research is supported by the Climate Change Research Hub of KAIST (Grant No. N01150138).



(a) The geometry and dimensions



(b) A close-up of the fatigue crack

Figure 1. Aluminum plate specimen used for the experimental validation

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Time-Domain Analysis of Resonant Acoustic Nonlinearity Arising from Cracks in Multilayer Ceramic Capacitors

---Ward L. Johnson, Sudook A. Kim, and Grady S. White, National Institute of Standards and Technology, 325 Broadway St., MS 647, Boulder, CO 80305; Jaemi Herzberger, University of Maryland, Department of Mechanical Engineering, College Park, MD 20742

---Acoustic nonlinearity of cracked and uncracked multilayer ceramic capacitors (MLCCs) was characterized through time-domain analysis of resonant waveforms following direct ferroelectric tone-burst excitation. The objective of this work was to establish a nondestructive method for detecting the presence of cracks in MLCCS and to demonstrate the general method of time-domain nonlinear analysis with tone-burst acoustic excitation. Cracks in MLCCS are often found to have no significant initial effect on the electrical characteristics but to evolve into conductive pathways during service. Our measurements employed a phase-sensitive receiver that enabled a determination of the phase of decaying oscillations (relative to a reference sinusoid) of a resonant mode near 1 MHz. In an acoustically nonlinear specimen, the frequency during resonant ringdown is dependent on time, as a consequence of the vibrational amplitude varying with time, and this leads to changes in slope of resonant phase versus time. Waveforms were analyzed by, first, fitting the recorded RF amplitude versus time to a decaying exponential and, then, inserting the parameters of this fit into a second function to fit the time-dependent phase, with amplitude dependence of the resonant frequency incorporated in this function. The measurements and analyses were performed on barium-titanate-based MLCCs with an X7R performance rating before and after quenching in ice water from elevated temperatures, which resulted in the generation of surface-breaking cracks in a fraction of the specimens. The presence of cracks in each specimen was determined through the use of a microscopic vicinal illumination technique. Measurements of nonlinear parameters of the capacitors before quenching were used to set a range corresponding to the 95 % confidence interval of a Gaussian fit to the distribution of these parameters, and the distributions of measurements obtained after heat treatment were compared with this range. The distribution of nonlinear parameters of heat-treated capacitors without visible cracks was found not to be significantly different than the reference distribution obtained from the as-received MLCCs. However, most capacitors with cracks were found to have nonlinear parameters outside of the reference range. These results indicate that time-domain nonlinear measurements with tone-burst excitation are a promising approach for nondestructively detecting cracks in MLCCs. They also illustrate the potential of this approach for rapid nonlinear acoustic detection of structural flaws in other materials.

4:30 PM

A Novel and Practical Approach for Determination of the Acoustic Nonlinearity Parameter Using a Pulse-Echo Method

---**Hyunjo Jeong**[1], Shuzeng Zhang[2], Sungjong Cho[1], Xiongbing Li[2], and Dan Barnard[3], [1]Division of Mechanical and Automotive Engineering, Wonkwang University, Iksan, Jeonbuk 570-749, Republic of Korea; [2]School of Traffic and Transportation Engineering, Central South University, Changsha, Hunan, 410075, China; [3]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011

---Measurements of the acoustic nonlinearity parameter β are frequently made for early detection of damage in various materials. The practical implementation of the measurement technique has been limited to the through-transmission setup for determining the nonlinearity parameter of the second harmonic wave. For the purpose of practical applications, a pulse-echo measurement technique is more desirable which enables the single-side access of test components. The issue with using the second harmonic wave reflected from the stress-free interface is that such a boundary destructively alters the nonlinear generation process and consequently makes it difficult to obtain the reliable results of β. In this work, a novel approach is proposed to use the third harmonic wave and to measure the corresponding nonlinearity parameter γ in a pulse-echo configuration. Starting from the Westervelt equation which describes the combined effects of nonlinearity, diffraction and attenuation, higher harmonic solutions of the quasilinear theory are derived. Furthermore, we develop a numerically efficient multi-Gaussian beam model that provides explicit formula for attenuation and diffraction corrections. It is shown from simulation that the stress-free boundary constructively generates the third harmonic wave. The nonlinearity parameter γ is then defined and its relation to the second harmonic parameter β is also established. Measurement results are presented on some representative samples, and the effects of diffraction are discussed.**---**This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (Grant No. 2013-R1A2A2A01016042), and by the National Natural Science Foundation of China (Grant Nos. 61271356, 51205031).

4:50 PM

Experimental Comparison of Nonlinear Parameters Obtained from Absolute Measurement and Relative Measurement

---**Jongbeom Kim**[1], Dong-Gi Song[1], Younho Cho[2], Chung-Seok Kim[3], and Kyung-Young Jhang[4],[1]Department of Mechanical Convergence Engineering, Hanyang University, Seoul, Republic of Korea, 133-791; [2]School of Mechanical Engineering, Pusan National University, Busan, South Korea, 609-735; [3]Department of Metallurgy and Materials Engineering, Chosun University, Gwangju, Republic of Korea, 501-759; [4]School of Mechanical Engineering, Hanyang University, Seoul, Republic of Korea, 133-791

---The ultrasonic nonlinear parameter β is obtained from the displacement of fundamental and second-harmonic frequency components, so it needs to measure the absolute displacement of fundamental and second-harmonic frequency components. However, the displacement of high-frequency harmonic component is not easily measured because that is very weak. Therefore, many researchers have measured a relative ultrasonic nonlinear parameter β` using the voltage amplitude of received signal instead of measuring absolute displacement. The parameter $\beta$` is more convenient than measuring the parameter β, which is effective to compare before and after damage of a material; however, the parameter β` has never been not verified in comparison with absolute ultrasonic nonlinear parameter. This study compares the relative parameter with the absolute parameter. First, the absolute ultrasonic nonlinear parameters of fused silica and Al6061 are obtained by using the piezoelectric detection method [1], and then the relative ultrasonic nonlinear parameters of same material are obtained by using the transmission method. After the experiment, the ratio of nonlinear parameter measured in fused silica to that measured in Al6061 is compared for the absolute and relative cases. The results of absolute and relative measurements were almost same. Consequently, β and β'can be applied equally when comparing before and after the damage.---This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (NRF-2013M2A2A9043241).

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Session 23

SESSION 23

NDE MODELING OF COMPOSITES

Cara Leckey, Chairperson

Nicollet D2

1:30 PM **Nondestructive Evaluation of Composites – Current AFRL Activities**
---**Eric Lindgren**, John Welter, David Mollenhauer, and Mark Flores, US Air Force Research Laboratory, Materials and Manufacturing Directorate, Structural Materials Division, WP AFB OH 45433

1:50 PM **Advances in Electromagnetic Models for Three-Dimensional Nondestructive Evaluation of Advanced Composites**
---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

2:10 PM **A Model-Based, Bayesian Characterization of Subsurface Corrosion Parameters in Composite Multi-Layered Structures**
---**Heather Reed**, Weidlinger Associates, Inc., New York, NY 10005; Wally Hoppe, University of Dayton Research Institute, Dayton, OH 45469

2:30 PM **Estimating Composite Material Condition Using Limited NDE Data and Bayesian Inference**
---**Elizabeth Gregory** and Stephen D. Holland, Center for Nondestructive Evaluation and Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

2:50 PM **Validation and Implementation of an Automated Data Analysis Algorithm**
---**J. T. Welter**[1], J. C. Aldrin[2], and D. Forsyth[3], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB OH 45433; [2]Computational Tools, Gurnee IL 60031; [3]TRI/Austin, Austin, TX 78746

3:10 PM ***Break***

3:30 PM **Challenges of Composite NDE Simulation Tool Development and Validation**
---**Cara A. C. Leckey**[1], Peter D. Juarez[1], and Jeffrey P. Seebo[2], [1]NASA Langley Research Center, Hampton VA 23681; [2]Analytical Mechanics Associates, Inc., Hampton VA 23681

3:50 PM **Numerical Simulations of Thermographic Responses in Composites**
---William P. Winfree, **K. Elliott Cramer**, Joseph N. Zalameda, and Patricia A. Howell, NASA Langley Research Center, Mail Stop 225, 5 West Taylor Street, Hampton, VA 23681

4:10 PM **3D Finite Element Modelling of Guided Wave Scattering at Delaminations in Composites**
---Bibi Intan Suraya Murat and **Paul Fromme**, University College London, Department of Mechanical Engineering, WC1E 7JE, United Kingdom

4:30 PM **Dispersion Loci of Guided Waves in Viscoelastic Composites of General Anisotropy**
---**F. Hernando Quintanilla**[1], Z. Fan[2], M. J. S. Lowe[1], and R. V. Craster[3]; [1]Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom; [2]School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798; [3]Department of Mathematics, Imperial College, London SW7 2AZ, United Kingdom

4:50 PM **Guided Wavefield Reconstruction from Sparse Measurements**
---**Olivier Mesnil**[1] and Massimo Ruzzene[1,2], [1]D. Guggenheim School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0150; [2]G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Altanta, GA 30332-0150

5:10 PM **Phase Congruency for Damage Mapping in Composites**
---**Aaron Darnton**, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology and Naval Undersea Warfare Center, Division Keyport, Atlanta, GA 30332-0150; Massimo Ruzzene, Daniel Guggenheim School of Aerospace Engineering and George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0150

1:30 PM

Nondestructive Evaluation of Composites – Current AFRL Activities

---Eric Lindgren, John Welter, David Mollenhauer, and Mark Flores, US Air Force Research Laboratory, Materials and Manufacturing Directorate, Structural Materials Division, WP AFB OH 45433

---Composites are experiencing continued growth as a material for use in aerospace systems. However, there continues to be constraints for their use, especially in US Air Force (USAF) applications, that can be linked in part to current nondestructive evaluation (NDE) methods used to assess the integrity of composites. This presentation provides an overview of research and development activities at the Air Force Research Laboratory (AFRL) to augment current NDE capability to meet emerging needs for expanded use of graphite fiber reinforced composites. One such area is in damage characterization, which is needed for damage progression modeling to enable damage tolerance approaches for the life management of composite structure. Damage tolerance is the preferred method used by USAF to manage the integrity (i.e. safety) of primary structure. Currently, the ability to predict damage evolution in composites remains at a research level and needs to be matured to be equivalent to the fracture mechanics-based methods used to that can predict slow crack growth for the safe management of metallic structures. However, to make this possible, NDE capability has to improve to meet the need to characterize existing damage in the composite to enable the accurate modeling of the damage evolution as s function of cyclic loads. This means expanding capability beyond current methods to detect delaminations to sizing them on a ply-by-ply basis. A second area is in using automation to assist the analysis of NDE data of composites. This addresses the current production bottleneck of analyzing the ultrasonic data generated by the quality control requirement for 100 percent inspection of all aerospace composites before they are put into use. Current practice has human analysis of all NDE data. To streamline this analysis process, automated analysis methods are being developed to assist the human interpretation of the NDE data. In addition to these two current efforts in graphite fiber reinforced composites, the presentation provides a brief overview of current efforts to address damage nucleation and progression in ceramic matrix composites.

1:50 PM

Advances in Electromagnetic Models for Three-Dimensional Nondestructive Evaluation of Advanced Composites

---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---In past work we have developed a rigorous electromagnetic model and an inversion algorithm for the three-dimensional NDE of advanced composite materials. This approach extends Victor Technologies' work in eddy-current NDE of conventional metals, and allows one to determine in localized regions the fiber-resin ratio in graphite-epoxy, and to determine those anomalies, e.g., delaminations, broken fibers, moisture content, etc., that can be reconstructed by our inversion method. In developing the model, we applied rigorous electromagnetic theory to determine a Green's function for a slb of anisotropic composite material, and then determine the integral relations for the forward and inverse problems using the Green's function. In addition, we have given examples of the solution of forward and inverse problems using these algorithms. In this paper we will build on the previous work and 1) demonstrate the value of electric circuit models in support of EM field calculations for characterizing cfrp composites; 2) demonstrate the value of our eddy-current modeling code, VIC-3D®, in modeling cfrp composites; 3) demonstrate that dielectric properties of cfrp composites can be included in EM (eddy-current) models; 4) use this result to demonstrate that eddy-currents can be used for the detection of FAWT (fiber areal weight) for graphite-epoxy prepegs, and; 5)make contact with the recent work of others in EM modeling composites.

2:10 PM

A Model-Based, Bayesian Characterization of Subsurface Corrosion Parameters in Composite Multi-Layered Structures

---Heather Reed, Weidlinger Associates, Inc., New York, NY 10005; Wally Hoppe, University of Dayton Research Institute, Dayton, OH 45469

---Thermographic NDE approaches to detect subsurface corrosion defects of multi-layered structures with composite top layers have proven traditionally difficult due to the fact that the thermal conductivity of composite materials is larger in lateral directions (the plane parallel to the surface) than in the through-thickness directions. This causes heat to dissipate faster laterally than through the thickness when a heat source is applied to the surface of the structure, making it difficult for subsurface damage effects to manifest on the surface, where the heat source and inspection typically occur. To address this, a heat induction approach is presented that excites the damaged, metallic bottom layer directly by Joule heating, resulting in more observable damage effects on the surface than what could be expected for traditional thermographic methods on this type of structure. To characterize the subsurface damage parameters (defect location, diameter, and depth), Bayesian inversion of numerically-simulated noisy data, using a high-fidelity, coupled electromagnetic – heat transfer model is employed. Stochastic estimation methods such as Markov chain Monte Carlo (MCMC) allow for quantification of uncertainty surrounding the damage parameters, which is important as this directly translates into uncertainty surrounding the component reliability. However, because thousands of high-fidelity finite element models are computationally costly to evaluate, as is typical in most MCMC methods, the use of Bayesian inversion is rarely feasible in real-time. To address this, a projection-based reduced order modeling (ROM) tracking and interpolation scheme [1] is formulated within the MCMC sampling method for the multi-physics problem, resulting in significant speedup of solution time with little loss of accuracy, enabling near-real time stochastic estimation of damage.

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2:30 PM

Estimating Composite Material Condition Using Limited NDE Data and Bayesian Inference

---**Elizabeth Gregory** and Stephen D. Holland, Center for Nondestructive Evaluation and Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---A method is proposed for tracking the condition of a composite part using Bayesian filtering of NDE data over the lifetime of the part. The Bayesian process builds off of the lifetime history of NDE scans and can give better estimates of material condition as compared to the most recent scan alone. Bayesian inference provides probabilistic estimates of damage condition that are updated as each new set of data becomes available [1]. In this demonstration, composite panels were fabricated, impacted to induce subsurface delaminations, loaded in compression until the damage was increased, and then the loading action was completed 4 more times. Flash thermography data was collected between each damage event to serve as a time history of the part. The flash thermography indicates some areas of damage but provides little additional information as the exact nature or depth of the damage. Computed tomography (CT) data was also collected after each damage event and provides high resolution volume model of damage that acts as 'truth'.

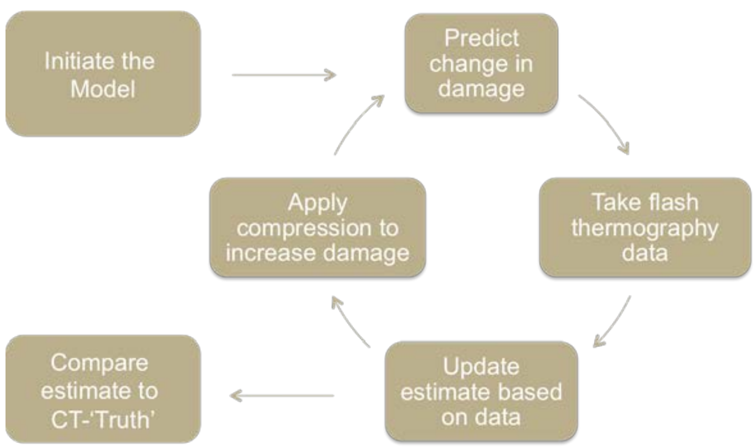

Figure 1. Bayesian filtering process.

Figure 1 describes the process by which the flash thermography data is incorporated into the condition estimate. After each cycle, the condition estimate is compared to "ground truth" from CT to evaluate the performance of the thermography-based condition tracking.

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2:50 PM

Validation and Implementation of an Automated Data Analysis Algorithm

---**J. T. Welter**[1], J. C. Aldrin[2], and D. Forsyth[3], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB OH 45433; [2]Computational Tools, Gurnee IL 60031; [3]TRI/Austin, Austin, TX 78746
---A process for validating and implementing an automated data analysis algorithm (ADA) for ultrasonic inspection data is presented. This topic is illustrated with examples from the on-going implementation of an ADA system that is to be used for composite part quality control inspections. Technical requirements will be discussed, and the need to involve the inspectors in the process. The necessary approval authorities for this case will be discussed as well. This paper will highlight the complexity of validating and implementing an ADA, and emphasize the importance of engaging stakeholders for buy in and sign off. ADA software features that help facilitate capability evaluation studies and support certification will also be presented.

3:30 PM

Challenges of Composite NDE Simulation Tool Development and Validation

---**Cara A. C. Leckey**[1], Peter D. Juarez[1], and Jeffrey P. Seebo[2], [1]NASA Langley Research Center, Hampton VA 23681; [2]Analytical Mechanics Associates, Inc., Hampton VA 23681

---Realistic nondestructive evaluation (NDE) simulation tools enable inspection optimization and predictions of inspectability for new aerospace materials and designs. NDE simulation tools may someday aid in the design and certification of advanced aerospace components; potentially shortening the time from material development to implementation by industry and government. Furthermore, modeling and simulation are expected to play a significant future role in validating the capabilities and limitations of guided wave based structural health monitoring (SHM) systems. The current state-of-the-art in ultrasonic NDE/SHM simulation cannot rapidly simulate damage detection techniques for large scale, complex geometry composite components/vehicles with realistic damage types. This paper discusses some of the challenges of model development and validation for composites, such as the level of realism and scale of simulation needed for NASA's applications. Ongoing model development work is described along with examples of model validation studies. The paper will also discuss examples of the use of simulation tools at NASA to develop new damage characterization methods, and associated challenges of validating those methods.

3:50 PM

Numerical Simulations of Thermographic Responses in Composites

---William P. Winfree, **K. Elliott Cramer**, Joseph N. Zalameda, and Patricia A. Howell, NASA Langley Research Center, Mail Stop 225, 5 West Taylor Street, Hampton, VA 23681

---Numerical simulations of thermographic responses in composite materials have been a useful for evaluating and optimizing thermographic analysis techniques. Numerical solutions are particularly beneficial for thermographic techniques, since the fabrication of specimens with realistic flaws is difficult. Simulations are presented with different ply layups that incorporated the anisotropic thermal properties that exist in each ply. The results are compared to analytical series solutions and thermal measurements on composites with flat bottom holes and delaminations.

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3D Finite Element Modelling of Guided Wave Scattering at Delaminations in Composites

---Bibi Intan Suraya Murat and **Paul Fromme**, University College London, Department of Mechanical Engineering, WC1E 7JE, United Kingdom

Carbon fiber laminate composites are increasingly used for aerospace structures as they offer a number of advantages including a good strength to weight ratio. However, impact during the operation and servicing of the aircraft can lead to barely visible and difficult to detect damage. Depending on the severity of the impact, delaminations can occur, reducing the load carrying capacity of the structure. Efficient nondestructive testing of composite panels can be achieved using guided ultrasonic waves propagating along the structure. The guided wave (A0 Lamb wave mode) scattering at delaminations was modelled using full three-dimensional Finite Element (FE) simulations. The influence of the delamination size and depth was systematically investigated from a parameter study. A significant influence of the delamination width on the guided wave scattering was found. The angular dependency of the scattered guided wave amplitude was calculated using a baseline subtraction method. The sensitivity of guided ultrasonic waves for the detection of delamination damage in composite panels is discussed.

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Dispersion Loci of Guided Waves in Viscoelastic Composites of General Anisotropy

---**F. Hernando Quintanilla**[1], Z. Fan[2], M. J. S. Lowe[1], and R. V. Craster[3], [1]Department of Mechanical Engineering Imperial College, London SW7 2AZ, United Kingdom; [2]School of Mechanical & Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, [3]Department of Mathematics, Imperial College, London SW7 2AZ, United Kingdom

---Dispersion curves of guided waves provide valuable information about the physical and elastic properties of waves propagating within a given waveguide structure. Algorithms to accurately compute these curves are an essential tool for engineers working in non-destructive evaluation, structure health monitoring and, more generally, for scientists studying wave phenomena. Therefore, it is of paramount importance to accurately model the material of the waveguide to obtain reliable and robust information about the guided waves that might be excited in the structure. A reasonable approximation to real solids is the perfectly elastic approach where the frictional losses within the solid are ignored. However, a more realistic approach is to model the solid as a viscoelastic medium with attenuation for which the dispersion curves of the modes are, in general, different from their elastic counterparts. This more realistic description is also motivated by the increasing introduction of composite materials in aerospace and aircraft structures. These materials exhibit damping which varies across the different modes, frequencies and directions of propagation. Dispersion curves are typically computed for low [1] or zero attenuation and presented in two or three dimensional [2] plots but they are troublesome to find, particularly when high values of attenuation are involved and arbitrary anisotropy is considered in single or multi-layered systems. In order to achieve robust and accurate results for viscoelasticity a spectral collocation method [3] is developed to compute the dispersion curves in generally anisotropic viscoelastic media in flat and cylindrical geometry. Two of the most popular models to account for material damping, Kelvin-Voigt [4] and Hysteric [1], are used in various cases of interest. Cases of high attenuation and arbitrary anisotropy are considered in single and multi-layered systems in both cylindrical and flat geometries, including examples of relevance to fiber composite structures.

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Guided Wavefield Reconstruction from Sparse Measurements

---**Olivier Mesnil**[1] and Massimo Ruzzene[1,2], [1]D. Guggenheim School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332; [2]G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---Guided wave measurements are at the basis of several Non-Destructive Evaluation (NDE) techniques. If sparse measurements of guided wave obtained using transducers arrays have been proven to efficiently detect and locate defects, full-field measurements acquired by Laser Doppler Vibrometers (LDV) can provide extensive information on the shape and subsurface location of defects. Wavefield acquisition from LDVs is generally a slow operation due to the fact that the phenomena to observe (wave propagation) must be repeated for each point measurement and the initial conditions must be achieved between each measurement. In this research, a Sparse Wavefield Reconstruction (SWR) process using Compressed Sensing[1] is developed. The goal of this technique is to reduce the number of samples needed to apply NDE techniques by at least one order of magnitude by extrapolating the knowledge of a few randomly chosen measurement pixels over an over-sampled grid. To achieve this, the lamb wave propagation equation[2] is used to formulate a basis of shape functions in which the wavefield has a sparse representation in order to comply with the Compressed Sensing requirements and use L1-minimization solvers. The main assumption of this reconstruction process is that every pixel on which the wavefield is to be reconstructed is a potential source of energy. The Compressed Sensing matrix is computed as being the contribution that would have been received at a measurement location from each possible source, using the dispersion relations of the specimen computed using a Semi-Analytical Finite Element technique[3]. The measurements are then processed through an L1 minimizer in order to find a minimum corresponding to the set of active sources and their corresponding excitation functions. This minimizer represents to the best combination of the parameters of the model to match the sparse measurements. Wavefields are then reconstructed using the propagation equation[2]. The set of active sources found by minimization contains all the wave excitation sources (such as PZT transducers) and scatters, and can therefore be used as source pre-location. Results are shown for unidimensional and bi-dimensional analytical wavefields as well as for an experimental wavefield in an anisotropic specimen with subsurface defect invisible to the naked eye. The work is funded by a collaborative agreement (NRANNH11ZEA001N VSST1) between NASA LaRC and Georgia Tech and the Strategic University Partnership between Boeing and Georgia Tech.

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5:10 PM

Phase Congruency for Damage Mapping in Composites

---**Aaron Darnton**, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology and Naval Undersea Warfare Center, Division Keyport, Atlanta, GA 30332-0150; Massimo Ruzzene, Daniel Guggenheim School of Aerospace Engineering and George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0150

---An efficient method for mapping damage is critical for assessing the severity of damage in a specimen. Phase congruency (PC) is a technique for detecting edges in images [1]. This technique will be adapted for damage mapping in composite plates. The proposed method would utilize time history measurements of a transient propagating guided wave. Each time step of the two-dimensional wavefield is then analyzed with the PC measure. The results of each time step are aggregated yielding a full field map of the specimen identifying the damage. This approach will be validated on analytical, numerical and experimental data sets for simulated delaminations in a composite plate. In concept, the PC measure exploits the fact that the phases of the frequency components of a signal have an equal value at a discontinuity. To do this, the measure compares the magnitude of the sum of the components to the sum of the magnitude of the components. When this ratio is unity, the phases of each the components are aligned. Additionally, a weighting factor is added to assess how broad band the signal is. A wide signal with a high degree of alignment is more meaningful than a narrow signal with a high degree of alignment. This measure must be adapted for the present case; a strong interrogating wave will be present dominating the wavenumber spectrum and narrowing the signal. In addition, it is known that higher wavenumber content contains the information relative to small wavelength features such as discontinuities. The method maybe adapted to favor the higher wavenumbers.
Preliminary results of the unmodified measure are shown below in Fig. 1. For comparison, a CT scan is presented as well. As can be seen, the PC method and CT scan show good agreement.
This work is funded by the US Navy under the In-house Laboratory, Independent Research program.

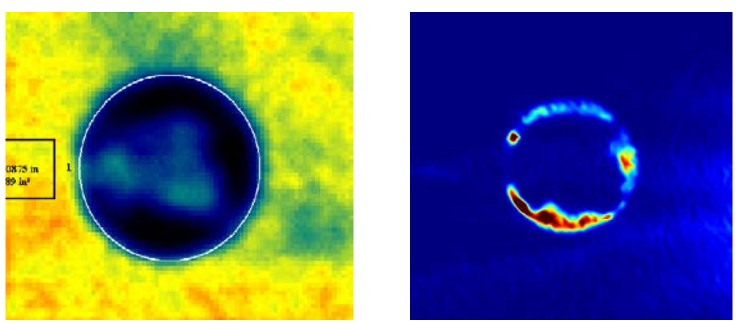

Figure 1. Comparison between CT scan (left) and damage map from the unmodified PC measure (right) of simulated delamination in a composite plate.

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Session 24

SESSION 24
ONE-SIDED ACCESS FOR CIVIL INFRASTRUCTURE CHARACTERIZATION
Dwight Clayton and Kyle Hoegh, Co-Chairperson
Nicollet D3

1:30 PM **Quantitative Ultrasonic Evaluation of Concrete Structures Using One-Sided Access**
---**Lev Khazanovich** and Kyle Hoegh, University of Minnesota, Department of Civil, Environmental and Geo- Engineering, Minneapolis, MN 55455

2:10 PM **Ultrasonic Surface Wave Energy Scatter to Characterize Cracking Damage in Concrete**
---**Suyun Ham**, John S. Popovics, and Michael L. Oelze, The University of Illinois at Urbana-Champaign, 205 N. Mathews Street, MC-250, Urbana, IL 61801

2:30 PM **Optimizing Data Collection Settings for Ultrasonic Evaluation of Defects in Diverse Environments**
---**Kyle Hoegh**[1], Lev Khazanovich[1], and Dwight Clayton[2]; [1]Department of Civil, Environmental and Geo- Engineering, University of Minnesota, Minneapolis, MN 55455; [2]Oak Ridge National Laboratory, Electrical and Electronics Systems Research Division, P. O. Box 2008 Oak Ridge, TN 37831

2:50 PM **Imaging and Characterization of Fracture Interface: An Experimental Study**
---**Fatemeh Pourahmadian**, Roman Tokmashev, Pierre-Augustin Risch, and Bojan B. Guzina, University of Minnesota, Department of Civil, Environmental & Geo-Engineering, Twin Cities, MN 55455

3:10 PM ***Break***

3:30 PM **Characterization of Concrete at Various Freeze Thaw Damage Conditions Using SH-Waves**
---**Katelyn Freeseman**, Kyle Hoegh, and Lev Khazanovich, University of Minnesota, Department of Civil, Environmental and Geo-Engineering, Minneapolis, MN 55455

3:50 PM **Compton Imaging Tomography for One-Sided Access NDE of Nuclear Power Plant Structures, Systems, and Components**
---**Volodymyr Romanov**, Victor Grubsky, and Keith Shoemaker, Physical Optics Corporation, Torrance, CA 90501

4:10 PM **Characterization of Moving Surface Loads with Buried Accelerometers**
---**Eyal Levenberg** and Oded Drori, Faculty of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel

4:30 PM **Inverse Dynamic Visco-Elastic Analysis of Pavement Deflections**
---**Abbas Booshehrian** and Lev Khazanovich, University of Minnesota, Department of Civil, Environmental and Geo- Engineering, Minneapolis, MN 55455

4:50 PM **Nondestructive Testing and Dynamic Monitoring of Wind Turbine Towers**
---**Chih-Hung Chiang**, Keng-Tsang Hsua, and Chia-Chi Cheng, Chaoyang University of Technology, Center for NDT and Department of Construction Engineering, Taichung, 413 TAIWAN ROC; Chih-Peng Yu, National Chung Hsin University, Department of Civil Engineering, Taichung, 402 TAIWAN ROC.

1:30 PM

Quantitative Ultrasonic Evaluation of Concrete Structures Using One-Sided Access

---**Lev Khazanovich** and Kyle Hoegh, University of Minnesota, Department of Civil, Environmental and Geo- Engineering, Minneapolis, MN 55455

---Ultrasonic testing uses high frequency (greater than 20,000 Hz) sound waves for inspecting a wide range of construction materials and structures. Although ultrasound has been used for evaluation of concrete structures since 1940s, earlier applications of this technology have experienced difficulties. Traditional ultrasonic methods relied on time consuming liquid coupling and could not achieve the necessary penetration depths in concrete materials due to the heterogeneity causing excessive attenuation of the wavefront. Recent introduction of dry point contact transducers and arrays offered an opportunity of significant improvement of productivity, penetration depth, and resolution of evaluation. The ultrasonic tomography device (MIRA), contains multiple transmitting and receiving DPC transducers. The synthetic aperture focusing technique (SAFT), as applied to elastic wave propagation, can be used to determine precise locations of changes in acoustic impedance when using spatially diverse measurement pairs. While traditional SAFT B-scans are useful for diagnostics of various problems, there are limitations that should be addressed. The limited aperture of the ultrasonic self- contained measurement system can cause inaccuracy when the defect is at the edge of the array or the area of interest is larger than the dimensions of the system. These limitations are address and procedures are applied for several practical civil engineering applications such as assessment of steel reinforcement and subsurface flaws. Figure 1 illustrates an example progression of imaging a steel reinforcement. A comparison with forensic verification activities demonstrates the effectiveness of the method.

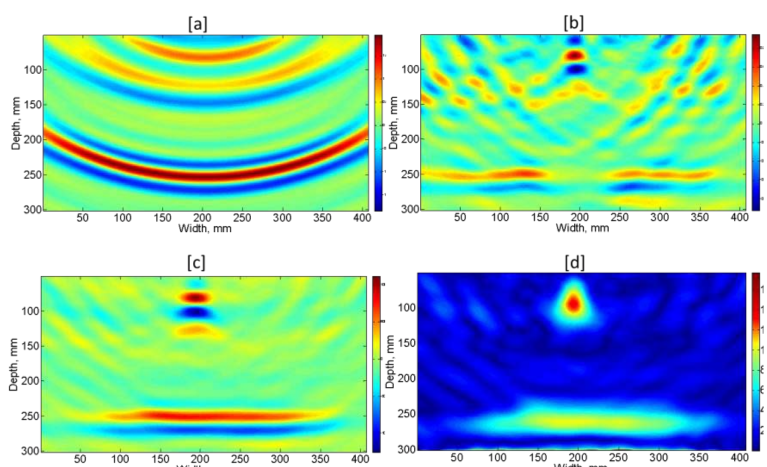

Figure 1. SAFT representation of an embedded steel reinforcement using (a) 4 transducer pairs,

(b) 9 adjacent transducer pairs, (c) 45 spatially diverse measurement pairs, and (d) instantaneous amplitude representation.

2:10 PM

Ultrasonic Surface Wave Energy Scatter to Characterize Cracking Damage in Concrete

---Suyun Ham, John S. Popovics, and Michael L. Oelze, The University of Illinois at Urbana-Champaign, 205 N. Mathews Street, MC-250, Urbana, IL 61801

---Contactless, air-coupled ultrasonic techniques offer much promise for rapid non-destructive evaluation (NDE) for large concrete structures. Contactless ultrasonic surface wave measurement is especially interesting for situations where access to only one surface of a structure is provided. Here we describe a recent research effort that applies contactless ultrasonic surface waves to concrete in order to determine the sensitivity of such measurements to the presence of distributed cracking damage in the concrete. The contactless sensor set, controlled scanning platform, signal processing schemes, and testing samples used in a set of experimental tests are described. The concrete test samples contain distributed cracking across a range of cracking extent, ranging from low to high crack volume density. Finite element simulation analyses and results from the experiments revealed that forward propagating surface wave group velocity and pulse attenuation (i.e. forward scattering) data were relatively insensitive to the presence of distributed cracking in concrete. On the other hand, backscattered surface wave energy measurements were much more sensitive to the presence of cracking. The backscattered energy was extracted from the total obtained signal using two different approaches: a time-domain subtraction approach and a spectral variance analysis approach. Both approaches provided consistent results that track well to internal cracking damage extent, comparable to standard resonance tests on companion samples. A large set of backscatter data collected across a sample illustrate the potential to use such data to image concrete surface and to identify localized regions of damage. The backscatter image results were compared with infrared thermograph and optical surface images of the sample.

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Optimizing Data Collection Settings for Ultrasonic Evaluation of Defects in Diverse Environments

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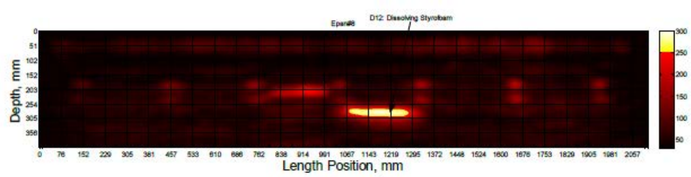
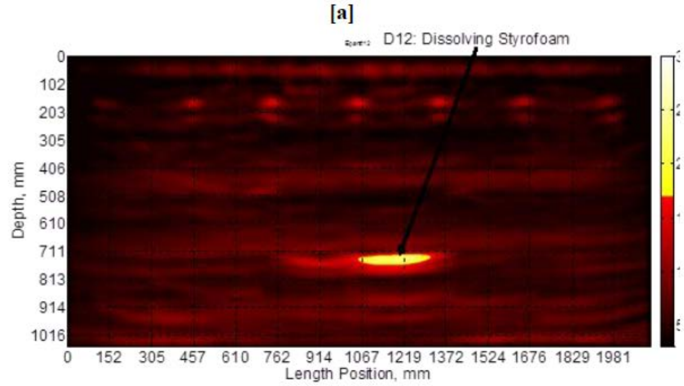
---Evaluation of large, heavily reinforced concrete structures involves many intrinsic difficulties in characterizing the internal condition. For example, the same defect size and type can cause a significantly different signal response depending on the depth or relative location to surrounding reinforcements. As such, data collection settings that allow for characterization of concrete condition in one environment, may not be well suited for characterization of concrete condition in another. Although large concrete samples that allow for comparative testing of various nondestructive evaluation (NDE) technologies and methods are not readily available, a reinforced concrete sample was constructed with simulated defects to represent NPP concrete structures. This specimen provided an opportunity to characterize the effect of the environment on selecting proper data collection settings. The potential for optimizing the data collection settings for the area or defect type of interest is explored in this paper using an ultrasonic linear array system. Figure 1 shows an example of the different results obtained from imaging the same defect at different depths. The volumetric imaging results of the ultrasonic array-based approach at different settings are presented along with a comparison with the designed defect characteristics in the representative NPP containment wall.



[a]



[b]

Figure 1. SAFT-Pan reconstruction showing the reflectivity at D12 as tested from the rough side of the specimen (shallower side of the specimen with respect to the defect). SAFT-Pan reconstruction showing the reflectivity at D12 as tested from the smooth side of the specimen (deeper side of the specimen with respect to the defect).

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Imaging and Characterization of Fracture Interface: An Experimental Study

---Fatemeh Pourahmadian, Roman Tokmashev, Pierre-Augustin Risch, and Bojan B. Guzina, University of Minnesota, Department of Civil, Environmental & Geo-Engineering, Twin Cities, MN 55455

---A systematic *experimental* investigation will be pursued to: i) verify a recently proposed inverse approach [1] for *simultaneous* reconstruction of fracture geometry and characterization of its interfacial condition at both low and high frequency regimes of illumination, and ii) better understand the nature of the contact condition in pre-existing, and possibly evolving, fractures in quasi-brittle materials. To this end, as illustrated in Fig. 1, slab-like laboratory specimens of *granite* and *sandstone* will be: a) induced with *non-planar* fractures, b) subjected to suitable static stress, and c) excited by O(10KHz) ultrasonic waves, while monitoring the induced surface motion over a high density of scanning grid. This will be accomplished with the aid of a *Scanning Laser Doppler Vibrometer* (SLDV) that is capable of tracking triaxial particle motion, with amplitudes down to O(nm) and frequencies up to 1MHz, over the surface of solid bodies. The SLDV measurements of the in-plane velocity field across the *surface array* S (Fig. 1) will be used to reconstruct the *full displacement field* $u(x,y,t)$ and, upon differentiation and use of the Hooke's law, the corresponding *stress field* $\sigma(x,y,t)$ in that region. Note that the particle displacements will be computed from the corresponding particle velocity data via an integration routine. From the local knowledge of u and σ, one can compute i) the fracture opening displacement (COD), and ii) tractions applied to the fracture surface, thus enabling *point-wise computation* of their correlation, and its evolution in time, which can be translated in terms of heterogeneous normal k_n and tangential k_s interfacial stiffnesses. Such obtained distributions of k_s and k_n will then be compared with their counterparts obtained earlier by applying the proposed seismic-tomography framework to the "remote" sensory data along linear arrays L1–L4 (Fig. 1). Moreover, such comparison will be repeated on applying the inverse solution to the *reduced* "remote" data to assess the effect of the source/receiver aperture on the quality of the inverse solution. For completeness, the effect of static stress and illumination frequency on the contact parameters and COD-traction relationship will be studied.

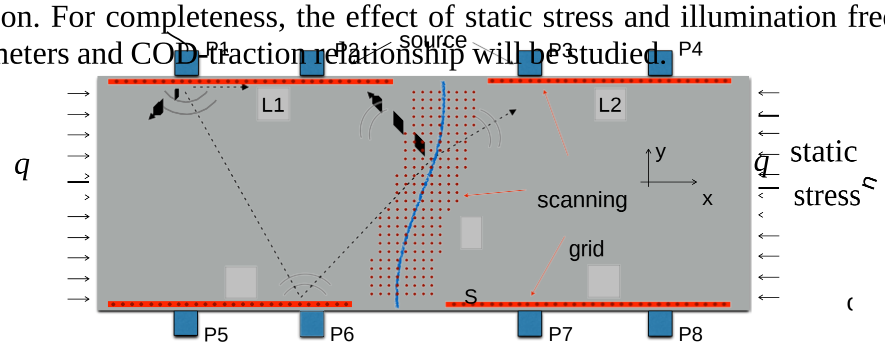

Figure 1. SLDV sensing setup including four *linear* arrays of "remote" triaxial sensors (L1–L4), a *surface* sensing array (S) covering the fracture, and eight piezoelectric source locations (P1–P8).

Reference:

1. F. Pourahmadian, B. B. Guzina, "On the elastic-wave imaging and characterization of fractures with specific stiffness", under review by *Int. J. Solids Struc.*, *arXiv* preprint arXiv: 1501.03525, 2015.

3:30 PM

Characterization of Concrete at Various Freeze-Thaw Damage Conditions Using SH-Waves

---**Katelyn Freeseman**, Kyle Hoegh, and Lev Khazanovich, University of Minnesota, Department of Civil, Environmental and Geo-Engineering, Minneapolis, MN 55455

---Evaluation of migration-based reconstructions can give a qualitative characterization of large scale or excessive subsurface damage. However, for detection of stochastic damage mechanisms such as freeze-thaw damage, evaluation of the individual time-history data can provide additional information. A comparison of the spatially diverse measurements on several concrete slabs with varying freeze-thaw damage levels is given in this study. Figure 1 shows the change in signal shape associated with scans on slabs with different levels of damage. Signal characterization scans of different levels of freeze-thaw damage at various transducer spacing is investigated. The results show promise for a SH-wave classification system applicable for nondestructive characterization of freeze-thaw damage conditions.

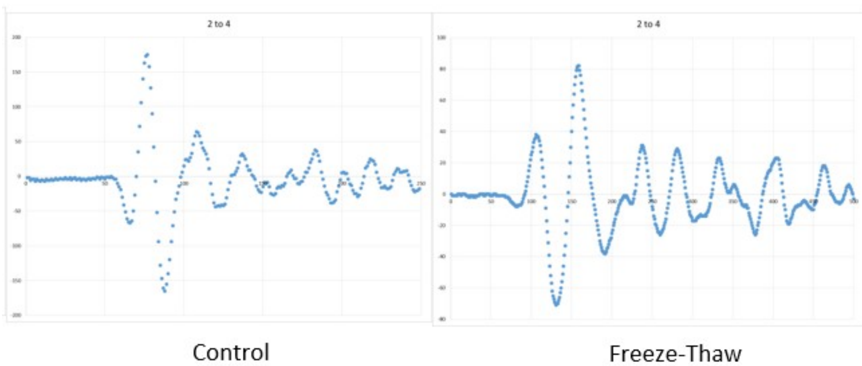

Figure 1. Raw signal results for a control slab with no designed damage (left) and for a slab with known freeze-thaw damage (right).

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Compton Imaging Tomography for One-Sided Access NDE of Nuclear Power Plant Structures, Systems, and Components

---Volodymyr Romanov, Victor Grubsky, and Keith Shoemaker, Physical Optics Corporation, Torrance, CA 90501

---Novel nondestructive evaluation (NDE) systems based on a recently pioneered Compton Imaging Tomography (CIT) technique [1, 2] are currently been developed by Physical Optics Corporation (POC). CIT provides high-resolution three-dimensional Compton scattered X-ray imaging of the internal structure of evaluated objects, using the set of acquired two-dimensional Compton scattered X-ray images of consecutive cross sections of these objects. Unlike conventional computerized tomography, CIT requires only one-sided access to objects, has no limitation on the dimensions and geometry of such objects, and can be applied to large multilayer nonuniform objects with complicated geometries. Also, CIT does not require any contact with objects during its application. We successfully demonstrated the feasibility of CIT-based systems for *in situ* NDE of nuclear power plant (NPP) structures, and components. Such NDE systems can identify and localize internal features (stress and fatigue cracks, corrosion, etc.) inside advanced materials that can withstand high-temperatures and high-radiation environments without significant degradation in strength and reliability over the lifetime of nuclear installations (existing and future Gen IV reactors and NPP installations: gas turbines, heat exchangers, etc.), including metallic alloys, carbon-carbon composites, and silicon carbide/silicon carbide composites. Also, a CIT-based system is a versatile tool for evaluating the effects of radiation damage on various types of nuclear reactor graphite, providing accurate graphite density measurements at various nuclear plant lifecycle stages. It can assist in the development of a science-based understanding of the fundamental mechanisms of the irradiation behavior of graphite in order to predict how new types and grades will behave in the future for Gen IV reactors. We have also successfully applied our system for *in-situ*, fast, and effective NDE of highly radioactive fuel tests in highly radioactive environments: investigation of geometric and compositional characteristics of nuclear fuel rods/assemblies in fuel tests that include disrupted fuel (e.g., failed cladding and fragmented fuel pellets, burn-up distribution, fuel location identification, and non-fuel component geometry) prior to disassembly. We also optimized our CIT-based system for fast and effective NDE of NPP cabling in conduit or in bundles to investigate their configuration, as well as the integrity of the insulation and internal wires. The authors would like to acknowledge the generous support of the U.S. DoE Office of Nuclear Energy (Grants: DE-SC0003345, DE-SC0009594, DE-SC0010146, DE-SC0011937, etc.).

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Characterization of Moving Surface Loads with Buried Accelerometers

---**Eyal Levenberg** and Oded Drori, Faculty of Civil and Environmental Engineering, Technion - Israel Institute of Technology, Technion City, Haifa 32000, Israel

---The advocated research idea in this work is characterizing moving surface loads from data collected by a cluster of subterranean sensors. The approach taken is based on sensing the mechanical responses generated inside the supporting medium by the passing event, i.e., load features are not directly targeted by the sensors - they are to be inferred from inverse modeling. The responses being sought are not propagating stress waves or acoustic signatures. While these carry pertinent information, they place high signal acquisition demands on the measurement system in terms of frequency response, sampling rate, and synchronization between sensors. In turn, the sought responses are quasi-static in nature - relatively slow occurring compared to wave speeds in the medium. This situation warrants the neglect of inertia effects in the modeling and therefore greatly simplifies the evaluation. The focus herein is on utilizing data collected by buried inertial sensors (accelerometers). Essentially, these devices measure velocity rates at their point of embedment in one, two, or three directions. The main reason for this choice is the fact that accelerometers are best suited for wireless applications and subsequently for subsurface deployment over wide areas [1]. The targeting of quasi-static responses lessens acquisition and power demands, and therefore complements (considerably) the wireless vision. It is important to note that if load characteristics are a priori known, the problem being addressed can be 'inverted' as means to extract in-place medium properties [2,3]. In a recent exploratory study [4], two synchronized inertial sensors were implanted in a low volume road (Figure 1, left). Vertical accelerations caused by lightweight vehicles passing at random near the sensors were recorded. It was observed from the raw measurements that the signals were dominated by high frequency content (Figure 1, top right). However, once these frequencies were removed by means of smoothing, the quasi-static response become clear (Figure 1, bottom right).

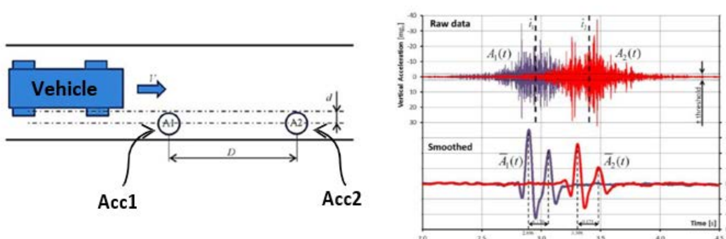

Figure 1. Field experiment and vertical in-pavement accelerations [3].

The purpose here is to first present the overall concept, then show some realistic (field) test data, and finally demonstrate its identification potential.

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Inverse Dynamic Visco-Elastic Analysis of Pavement Deflections

---**Abbas Booshehrian** and Lev Khazanovich, University of Minnesota, Department of Civil, Environmental and Geo- Engineering, Minneapolis, MN 55455

---The Falling Weight Deflectometer (FWD) is the most commonly used device for non-destructive pavement characterization. FWD applies a dynamic load to the pavement surface to simulate the conditions experienced by a pavement under a moving axle load. The time history of the surface deflections are recorded using sensors placed at different distances from the center of loading. The dynamic inverse analysis tries to backcalculate the pavement properties by matching the entire measured deflection history with the deflections calculated by the dynamic forward analysis. Although the nature of FWD is *dynamic*, the most common approach for interpreting FWD data is *static* inverse analysis, which determines the layer elastic properties by matching the measured maximum deflections with the deflections calculated from the layered elastic or Westergaard model. The main reason for this discrepancy is the inaccuracy and the complexity of the available inverse dynamic analysis. In this paper, generalized Westergaard model is introduced and its ability in capturing the behavior of both flexible and rigid pavements under dynamic loading is investigated. The generalized Westergaard model is consisted of a viscoelastic plate resting on a Winkler foundation that accounts for inertia and damping effects of the subgrade (Figure 1). The pavement response to Falling Weight Deflectometer (FWD) loading is simulated, and a semi-analytical solution involving the use of a Hankel transform in space and a finite difference method in time is developed. Application of this analysis on collected FWD data shows that the proposed inverse analysis is a promising tool to dynamically backcalculate the properties of both rigid and flexible pavements with considerable accuracy.

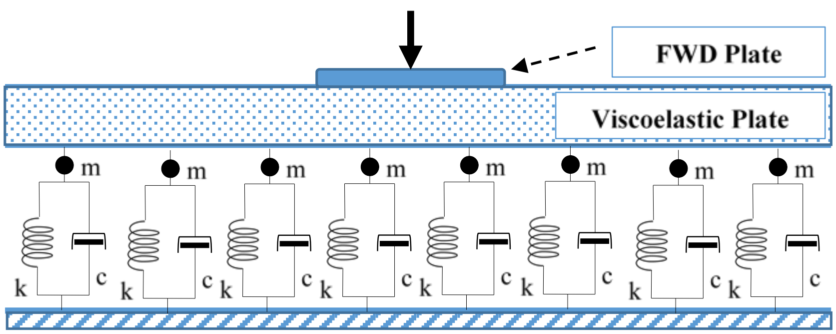

Figure 1. Generalized Westergaard Model

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Nondestructive Testing and Dynamic Monitoring of Wind Turbine Towers

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---The structural integrity is of great importance for maintaining the safety, reliability, and availability of utility tower structures. Wind turbine towers are in need of condition monitoring so as to lower the cost of unexpected maintenance. Technicians who perform visual inspection are at high risk because of the height of towers. Current research aims to apply remote inspection and monitoring techniques to tower structures so as to reduce the risk of inspection. Remote microwave interferometry and structural dynamic analyses have been explored in this respect. The results indicated that factors affecting the dominant frequencies of the tower include wind gust and possibly the blade movement. The lower part of the tower is sensitive to the change of stiffness as the decrease in dominant frequency indicates based on numerical simulation. Work in progress includes additional measurements of wind turbine towers using microwave interferometry and reassigned time-frequency representations of measurement data. The final outcome should provide more insight to the structural vibration of towers and develop the remote monitoring procedures and nondestructive evaluation techniques for local utility tower structures in Taiwan---Part of the research funding is provided by the National Science Council through the project NSC 102-2221-E-324 -015 and Ministry of Technology through the project MOST 103-2221-E-324 -003.

Session 25

SESSION 25
SENSORS
Matthias Pelkner and Thomas Eason, Chairpersons
Lakeshore C

1:30 PM **Development of Adapted GMR-Probes for Automated Detection of Hidden Defects in Thin Steel Sheets**
---**Matthias Pelkner**[1], Thomas Erthner[1], Rainer Pohl[1], Colin Commandeur[2], and Marc Kreutzbruck[3], [1]BAM, Federal Institute for Materials Research and Testing, 12200 Berlin, Germany; [2]Tata Steel, 1970 CA Ijmuiden, The Netherlands; [3]IKT Institut fuer Kunststofftechnick, Stuttgart, Germany

1:50 PM **Abnormality Detection of Induction Motor Using Standstill Impedance Measurement**
---**Sung Min Shin** and Hyun Gook Kang, Korea Advanced Institute of Science and Technology (KAIST), Department of Nuclear and Quantum Engineering, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701,Republic of Korea

2:10 PM **Non-Intrusive Measurement of Inner Bore Temperature of Small Arms Using Integrated Ultrasonic Transducers**
---**Daniel Lévesque**, Silvio Kruger, Jean-Pierre Monchalin, Martin Lord, and André Beauchesne, National Research Council Canada, Boucherville, QC, Canada; Rogerio Pimentel, Robert Stowe, and Franklin Wong, Defence Research and Development Canada, Valcartier, QC, Canada

2:30 PM **Nonlinear Rayleigh Wave Sound Fields Generated by a Wedge Transducer: Theory and Experiment**
---**Shuzeng Zhang**[1], Hyunjo Jeong[2], Sungjong Cho[2], and Xiongbing Li[1], [1]School of Traffic and Transportation Engineering, Central South University, Changsha, Hunan, 410075, China; [2]Division of Mechanical and Automotive Engineering, Wonkwang University, Iksan, Jeonbuk 5770-749, Republic of Korea

2:50 PM **Development of Flexible SAW Sensors for Non-Destructive Testing of Structure**
---**R. Takpara**[1,2], M. Duquennoy[1], C. Courtois[2], M. Gonon[3], M. Ouaftouh[1], G. Martic[4], M. Rguiti[2], and F. Jenot[1], [1]IEMN-DOAE, Université de Valenciennes, Le Mont Houy, 59313 Valenciennes, France; [2]LMCPA, Université de Valenciennes, PECMA, Z.I. Champ de l'Abbesse, 59600 Maubeuge, France; [3]UMONS, Université de Mons, Place du parc, 4 B7000 Mons – Belgique, [4]CRIBC (membre d'EMRA), 4, Avenue Gouverneur Cornez, 7000 Mons, Belgique

3:10 PM ***Break***

3:30 PM **Robotic and Hand-Held Time Domain Terahertz Thickness Measurement of Multi-Layer Aircraft Coatings**
---**David A. Zimdars** and Jeffrey S. White, Picometrix, LLC., an Advanced Photonix, Inc. Company, Ann Arbor, MI 48104; Juan G. Calzada and Bryan Foos, Air Force Research Laboratory, Wright-Patterson AFB OH 45433

3:50 PM **Microwave Sensor Design for Noncontact Process Monitoring at Elevated Temperature**
---**Yugandhara Rao Yadam**[1] and Kavitha Arunachalam[2], Indian Institute of Technology Madras, Electromagnetic Research Laboratory, Department of Engineering Design, Chennai, Tamilnadu, India 600036

4:10 PM **Quantitative Analysis of Damage Localization for Multi-Layer Composite Structures by Energy Based Acoustic Emission Source Location**
---**Dong-Jin Yoon**[1], Byeong-Hee Han[1], Il-Sik Kim[1], Choon-Su Park[1], and Il-Bum Kwon[1], [1]Center for Safety Measurement, Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon, 305-340, Republic of Korea

4:30 PM **Improved Semi-analytical Simulation of UT Inspections Using a Ray-Based Decomposition of the Incident Fields**
---**Vincent Dorval**, Nicolas Leymarie, and Sylvain Chatillon, CEA LIST, F-91191 Gif-sur-Yvette, France

1:30 PM

Development of Adapted GMR-Probes for Automated Detection of Hidden Defects in Thin Steel Sheets

---**Matthias Pelkner**[1], Thomas Erthner[1], Rainer Pohl[1], Colin Commandeur[2], Marc Kreutzbruck[3], [1]BAM, Federal Institute for Materials Research and Testing, 12200 Berlin, Germany; [2]Tata Steel, 1970 CA Ijmuiden, The Netherlands; [3]IKT Institut fuer Kunststofftechnick, Stuttgart, Germany

---Thin steel sheets with a thickness of 0.3 mm and less are the base materials of a great many products for our everyday life (cans, batteries, etc.). Potential inhomogeneities such as non-metallic inclusions inside the steel can lead to a rupture of the sheets during further production steps and such sheets with inclusions are unusable for subsequent processing. Therefore, there is a need to develop automated NDT techniques to detect hidden defects and inclusions in thin sheets during production. For this purpose Tata Steel Europe, Europe's second largest steel producer and BAM, the Federal Institute for Materials Research and Testing (Germany), collaborate in order to develop an automated NDT-system. This system has to be robust against external influences, especially when incorporated in an industrial environment. In addition, such a facility has to achieve a high sensitivity and a high spatial resolution in terms of detecting small inclusions in the µm-regime. In a first step, we carried out a feasibility study to determine which testing method is promising for detecting hidden defects and inclusions inside ferrous thin steel sheets. Therefore, two methods were investigated in more detail – MFL testing (magnetic flux leakage) using GMR sensor arrays (giant magneto resistance) as receivers [1,2] and eddy current testing (ET). The capabilities of both methods were tested with steel samples (0.2 mm thick) containing small defects with depths ranging from 5 µm up to 60 µm. Only in case of GMR-MFL-testing, we were able to detect parts of the hidden defects trustworthily with a SNR better than 10 dB. Here, the lift off between sensor and surface was 250 µm. On this basis, we investigated different testing scenarios including velocity tests and different lift offs. In this contribution we present the results of the feasibility study leading to first prototypes of GMR-probes which are now installed as part of a demonstrator inside a production line.

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Abnormality Detection of Induction Motor Using Standstill Impedance Measurement

---**Sung Min Shin** and Hyun Gook Kang, Korea Advanced Institute of Science and Technology (KAIST), Department of Nuclear and Quantum Engineering, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

---In many cases, the plant safety greatly depends on the successful operation of specific standby equipment which is powered by induction motor. Although soundness of the motor is very important, the motor itself does not provide any information for the perception of condition when it is not in operation. Currently, periodic surveillance test is being performed to check its abnormalities. However, frequent surveillance tests lead additional aging effect and system unavailable time. But if some inspection method is not entail actual equipment operation, these adverse effects are avoidable. From this point of view, impedance analysis could be an effective method for monitoring of motor soundness. For better understanding and prediction of probable abnormalities, equivalent circuit of induction motor needed to be developed. Each equivalent circuit parameter (ECP) has correlation with specific subcomponent (or geometry) of the motor and influences impedance measure to a specific trend. Therefore equivalent circuit can work like a map between impedance changes and possible abnormalities [1]. In this study, changes in impedance measure according to abnormal cases and underlying principles of them were analyzed. Here the abnormal cases referred to operating experience of motor operated valves (MOVs) in power plants in USA 1980-2000 [2]. Representative abnormal cases about induction motor are water intrusion, insulation breakdown, normal aging, and burning up. The abnormal cases are artificially reproduced and then the impedance changes are measured. Among the cases, figure 1 shows the changes of impedance measure at standstill around resonance frequency caused by water intrusion (excessive condensation). By utilizing impedance measure at standstill, abnormalities in motor could be identified without actual operation and maintained immediately. Thus, this approach can enhance the availability of standby equipment by reducing the time portion of failed but overlooked state.

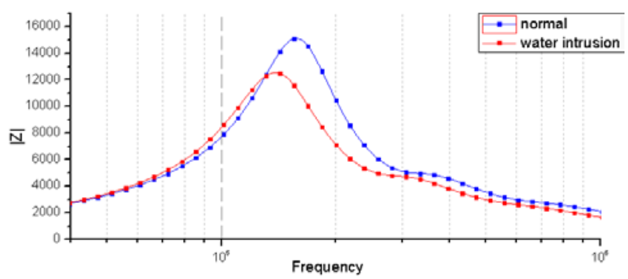

Figure 1. Changes of impedance measure caused by excessive condensation.

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Non-Intrusive Measurement of Inner Bore Temperature of Small Arms Using Integrated Ultrasonic Transducers

---**Daniel Lévesque**, Silvio Kruger, Jean-Pierre Monchalin, Martin Lord, and André Beauchesne, National Research Council Canada, Boucherville, QC, Canada; Rogerio Pimentel, Robert Stowe, and Franklin Wong, Defence Research and Development Canada, Valcartier, QC, Canada

---Management of thermal input to a small arms weapons system is a significant design and operational constraint. The operational effects can be serious including reduced accuracy of fire, reduced barrel life, melting of essential electronic system components, ammunition cook-off, burning of the soldier's skin and increased visible and IR signature and thus increase detectability. A collaborative project was recently initiated with the objective to measure non-intrusively the inner bore barrel temperature of a small arm during an actual firing. The approach uses integrated ultrasonic transducers (IUT) and the velocity temperature dependence of the longitudinal wave propagating through thickness. IUT was successfully implemented on a small arm at 3 locations and results from the tests at different firing rates are presented. The small but systematic increase in ultrasonic time delay of about 1 ns after each firing shot is well predicted by a simple 1D model of heat conduction and measured temperature rises are consistent with the thicknesses at different locations. The evaluation of the peak inner bore temperatures using IUT and their validation using eroding surface thermocouples at three different positions in the barrel are discussed.

2:30 PM

Nonlinear Rayleigh Wave Sound Fields Generated by a Wedge Transducer: Theory and Experiment

---**Shuzeng Zhang**[1*], Hyunjo Jeong[2], Sungjong Cho[2], and Xiongbing Li[1], [1]School of Traffic and Transportation Engineering, Central South University, Changsha, Hunan, 410075, China; [2]Division of Mechanical and Automotive Engineering, Wonkwang University, Iksan, Jeonbuk 570-749, Republic of Korea

---Linear and nonlinear Rayleigh wave sound fields generated by a wedge transducer are modeled and verified experimentally. The calculated area sound sources are used to model the linear Rayleigh sound fields on the sample surface, which are more accurate than the previously assumed uniform or Gaussian line source. A more general nonlinear Rayleigh wave equation is developed and the solutions with quasilinear theory are obtained. The second harmonic sound field is given in an integral expression with the linear Rayleigh wave acting as a forcing function. The sound fields are simulated and some important aspects are discussed. The receiving process of the propagated Rayleigh wave is analyzed for different types of transducers, and the received sound field distributions are presented. A multi-Gaussian beam model is employed to simplify the calculation process and to extract the diffraction and attenuation correction terms. The Rayleigh sound fields generated by the wedge transducer are verified through experiments, and good agreements between theory and experiment are observed, which proves the proposed method is more effective in predicting the Rayleigh sound fields generated by wedge transducers.**---**This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (Grant No. 2013-R1A2A2A01016042), and by the National Natural Science Foundation of China (Grant Nos. 61271356, 51205031).

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Development of Flexible SAW Sensors for Non-Destructive Testing of Structure

---**R. Takpara**[1,2], M. Duquennoy[1], C. Courtois[2], M. Gonon[3], M. Ouaftouh[1], G. Martic[4], M. Rguiti[2], and F. Jenot[1], [1]IEMN-DOAE, Université de Valenciennes, Le Mont Houy, 59313 Valenciennes, France; [2]LMCPA, Université de Valenciennes, PECMA, Z.I. Champ de l'Abbesse, 59600 Maubeuge, France; [3]UMONS, Université de Mons, Place du parc, 4 B7000 Mons – Belgique, [4]CRIBC (membre d'EMRA), 4, Avenue Gouverneur Cornez, 7000 Mons, Belgique

---In order to accurately examine the surface of structures, it is interesting to use surface SAW (Surface Acoustic Wave). Such transducers are well suited for example to detect early emerging cracks or to test the quality of a coating. On the other hand, when the coatings are thin or when emergent cracks are precocious, it is necessary to excite surface waves beyond 10MHz. Finally, when characterized structures are not flat, it makes sense to have flexible or conformable sensors. To address this problem, we propose to develop SAW type of interdigital sensors (or IDT for InterDigital Transducer), based on flexible piezoelectric plates. Initially, in order to optimize these sensors, we modeled the behavior of these sensors and identified the optimum characteristic sizes. In particular, the thickness of the piezoelectric plate and the width of the interdigital electrodes have been studied. Secondly, we made composites based on barium titanate foams (3-3 connectivity piezoelectric composite) in order to have flexible piezoelectric plates and to carry out thereafter sensors. Then, we studied several techniques in order to optimize the interdigitated electrode deposition on this type of material. One of the difficulties concerns the fineness of these electrodes because the ratio between the length (typically several millimeters) and the width (a few tens of micrometers) of electrodes is very high. Finally, mechanical, electrical and acoustical characterizations of the sensors deposited on aluminum substrates were able to show the quality of our achievement.

3:30 PM

Robotic and Hand-Held Time Domain Terahertz Thickness Measurement of Multi-Layer Aircraft Coatings

---**David A. Zimdars** and Jeffrey S. White, Picometrix, LLC., an Advanced Photonix, Inc. Company, Ann Arbor, MI 48104; Juan G. Calzada and Bryan Foos, Air Force Research Laboratory, Wright-Patterson AFB OH 45433

---Certain aircraft coatings must be applied with a tight thickness tolerance for proper performance. Often these coatings are applied in multi-layer stacks. Time domain terahertz (TD-THz) measurement methods of multi-layer specialty aircraft coatings are demonstrated using both a robotically mounted sensor and a sensor configured for hand-held use. TD-THz reflection tomography is an electromagnetic analog to ultrasound tomography (UT). TD-THz reflection tomography can determine the thickness of each individual layer in a coating stack simultaneously by analyzing a single recorded waveform (terahertz A-scan). However unlike UT (or single layer eddy current thickness measurement), the terahertz measurement method is non-contact. This allows a terahertz sensor to be mounted on coating spray robot and measure the thickness of the wet coating coincident with the spray plume (Figure 1). A hand-held version of the terahertz sensor may make measurements on dry coating stacks without the use coupling agent (as in UT). Unlike single layer eddy current or magnetic thickness measurement methods, the terahertz method is not sensitive to substrate composition or curvature (e.g. the terahertz method will read the same thickness over a fastener of a different material than the substrate). Gage repeatability and reproducibility studies demonstrate that the TD-THz multi-layer thickness measurement sensors are able to determine the thickness of cured coatings with a total gage of 0.00007 in. (0.07 mils or 1.8 μm) for a coating range of 39 to 74 mils with a standard deviation of the bias of <0.5 mils. The measurement system consists of the T-Ray 5000 series control unit which is connected to either a miniature TD-THz reflection sensor via a flexible umbilical 30 meters in length mounted onto an existing robot arm within a paint booth or a hand-held probe with LCD touch screen display (Figure 2). The robot mounted spray sensor has been Class I Div. 1 certified for use in a flammable atmosphere. The fiber optic coupled TD-THz technology employed is well suited to the application, as the sensors are small, light weight, and freely positionable.---This work was funded in part by Air Force Research Lab contracts FA8650-08-C-5006 and FA8650-12-C-5194. Picometrix would like to thank the Air Force Research Lab for their generous support.

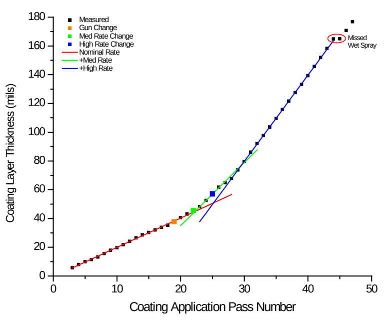

Figure 2 (Left) Terahertz Measurement of Wet Coating Thickness Per Spray Pass

Figure 3 (Right) Terahertz Multi-Layer Coating Thickness Gauge with Hand-Held Probe

3:50 PM

Microwave Sensor Design for Noncontact Process Monitoring at Elevated Temperature

---**Yugandhara Rao Yadam**[1] and Kavitha Arunachalam[2], Indian Institute of Technology Madras, Electromagnetic Research Laboratory, Department of Engineering Design, Chennai, Tamilnadu, India 600036

---In this work we present a microwave sensor for noncontact monitoring of level and height of dielectric layers in a high temperature environment. The sensor is a high gain, directional conical lensed horn antenna with narrow beam width (BW) designed for operation over 10 GHz – 15 GHz. Sensor design and optimization was carried out using 3D finite element method based electromagnetic (EM) simulation software HFSS®. A rectangular to circular waveguide feed was designed to convert TE_{10} to TE_{11} mode for wave propagation in the conical horn. Swept frequency simulations were carried out to optimize antenna flare angle and length to achieve better than –10 dB return loss (S_{11}), standing wave ratio (SWR) less than 2.0, 20° half power BW (HPBW) and 15 dB gain over 10 GHz – 15 GHz. Transient simulations were carried for a monopulse centered at 12.5 GHz to study time domain reflectometry (TDR) for a bi-layered dielectric medium at 300 °C – 700 °C located 300 mm from the sensing antenna. The sensor was fabricated using Aluminum and was characterized in an anechoic test box using a vector network analyzer (E5071C, Agilent Technologies, USA). Sensor characterization results indicate less than –12 dB S_{11} and SWR < 2.0 over 10 GHz – 15 GHz and 20° HPBW in the vertical plane at the lowest frequency (10 GHz). Antenna radiation pattern measurements are directional in agreement with simulation results. Preliminary high temperature transient simulations indicate the ability to detect 50 mm thick layers with dielectric contrast of $\Delta\varepsilon' \leq 1$. Experimental validation of the proposed noncontact microwave sensor will be presented for level detection at higher temperatures.**---**This work was funded by the Board of Research in Nuclear Sciences, India.

4:10 PM

Quantitative Analysis of Damage Localization for Multi-Layer Composite Structures by Energy Based Acoustic Emission Source Location

---Dong-Jin Yoon[1], Byeong-Hee Han[1], Il-Sik Kim[1], Choon-Su Park[1], and Il-Bum Kwon[1]
[1] Center for Safety Measurement, Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon, 305-340, Republic of Korea

---This paper describes on the new concept of damage localization, since there is some limitation in conventional acoustic emission source location method which strongly depends on the wave speed in the corresponding material like multi-layered composite structures. A new proposed source location method should be less affected by the wave speed in these kinds of composite material structure. In order to satisfy these conditions, we have developed a new source location algorithm which is based on the acoustic emission energy contour map. This measurement of energy distribution in the composite materials is better than time arrival difference method in its detectability point of view. It is also better to install minimum number of sensors on the structures to be covered. In this study, in order to verify the excellence of damage localization in the multi-layered composite structures, we have used 4 types of high pressure cylindrical composite vessel specimens as shown in Figure 1. It was found that acoustic emission signal energy was affected by its type of source, their material being used and its path of wave propagation. This kind of database for signal energy provides valuable information for assessing the damage localization of tested vessel. From the experimental results, the proposed new energy based AE analysis is verified for exact locating the damage sources in the multi-layered cylindrical composite structures. And also it gives more quantitative analysis results of comparable database for several types of vessel. The future work for embedded acoustic emission sensor application will be carried out in the next scheme.

Figure 1. Test specimen; steel, carbon and glass fiber composites with metal liner

4:30 PM

Improved Semi-Analytical Simulation of UT Inspections Using a Ray-Based Decomposition of the Incident Fields

---**Vincent Dorval**, Nicolas Leymarie, and Sylvain Chatillon, CEA LIST, F-91191 Gif-sur-Yvette, France

---Semi-analytical models are often used for computationally efficient ultrasonic simulations such as those proposed by Thompson and Gray [1] and by Schmerr and Song [2], as well as those implemented in the CIVA software [3]. They typically apply plane-wave approximations to the ultrasonic fields at the location of flaws in order to calculate diffraction coefficients. In favorable cases, plane-wave approximations yield satisfying results. However, they can lead to significant inaccuracies in unfavorable cases, such as for wide probe apertures, outside of the focal region, or for beam-splitting or distortion due to irregular geometries. This communication presents an improved model, implemented in a development version of the CIVA software. The new approach describes the ultrasonic field as a sum of rays and applies the plane-wave approximation to each ray instead of the entire field. It significantly improves the accuracy of echo computations. However, it implies that the diffraction is calculated for each pair of incident and diffracted rays instead of being calculated only once: a specific algorithm has been developed in order to avoid a significant increase in computation times. The significant benefits of the new approach are illustrated by comparing its results and computation times to those of the former plane-wave model in several cases of interest. They are also compared to those of a finite element model (CIVA-Athena).

References:

1. R. B. Thompson and T. A. Gray, "A model relating ultrasonic scattering measurements through liquid–solid interfaces to unbounded medium scattering amplitudes", J. Acoust. Soc. Am., 74 (4), pp. 1279-90 (1983).
2. L. W. Schmerr and J. S. Song, "Ultrasonic Nondestructive Evaluation Systems: Models and Measurements", Springer: New York, NY, USA, 2007.
3. S. Mahaut, M. Darmon, S. Chatillon, F. Jenson and P. Calmon, "Recent advances and current trends of ultrasonic modelling in CIVA", Insight 51, pp. 78-81 (2009).

Session 26

SESSION 26
6th EAW
Lakeshore A

OPEN SPACE
Ralf Holstein and Greg Selby

1:30 PM **5…..6 Different Discussion Groups with Moderators**

How to Live Holistic Reliability Concepts?
Flow of Information

Balance Between Regulations and Culture?
How to Overcome the “Delta”?

3:10 PM ***Break***

PRESENTATION OF GROUP SUMMARIES/EVALUATION OF THE WORKSHOP
Christina Mueller

4:10 PM **Summaries/Evaluation of Workshop**

5:40 PM **End of Workshop**

THURSDAY

THURSDAY, JULY 30, 2015

	Session 27 **X-Ray, CT and Radiography Methods I** ***Lakeshore A***	**Session 28** **NDE of Characterization** ***Nicollet D2***	**Session 29** **Nonlinear Ultrasonics** ***Nicollet D3***	**Session 30** **Nuclear** ***Nicollet D1***
8:30 AM				
8:50				
9:10				
9:30				
9:50				
10:10	COFFEE BREAK			
10:30				
10:50				
11:10				
11:30				
11:50				
12:10 PM	LUNCH			

Session 31 – PROFESSIONAL POSTERS – 1:30 – 3:10 PM – *Nicollet AB*

	Session 32 **X-Ray, CT, and Radiography Methods II** ***Lakeshore A***	**Session 33** **Pipelines and Automation** ***Nicollet D1***	**Session 34** **UT Microstructural Scattering** ***Nicollet D2***	**Session 35** **Benchmarks** ***Nicollet D3***
3:10	COFFEE BREAK			
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Session 27

SESSION 27
X-RAY, CT, AND RADIOGRAPHIC METHODS I
Uwe Ewert and Joe Gray, Co-Chairpersons
Lakeshore A

8:30 AM **Radiographic Applications in Micro Electronic Industries**
---P. Krüger[1], **N. Meyendorf**[1], M. Oppermann[2], P. Sättler[1] and K.-J. Wolter[2], [1]Fraunhofer IKTS-MD, Berlin and Dresden, [2]Technische Universitaet Dresden, Electronics Packaging Lab. (IAVT), Germany

8:50 AM **MOVED TO SESSION 32 - Multi-Scale X-Ray Romography for Advanced Packaging: From Micro to Nano**
---**Ehrenfried Zschech**[1,2], Markus Loeffler[2], Juergen Gluch[1], [1]Fraunhofer IKTS-MD Dresden, Germany; [2]Technische Universität Dresden, Dresden Center for Nanoanalysis (DCN) and Center for Advancing Electronics Dresden (cfaed), Germany

9:10 AM **Implementation and Evaluation of Two Helical CT Reconstruction Algorithms in CIVA**
---**Hussein Banjak**[1,2], Marius Costin[1], Caroline Vienne[1], and Valérie Kaftandjian[2], [1]CEA, LIST, Département Imagerie et Simulation pour le Contrôle, F-91191 Gif-sur-Yvette, France; [2]LVA, Laboratoire Vibrations Acoustique, INSA-Lyon, F-69621 Villeurbanne, France

9:30 AM **Application of Offset-CT Scanning to the Inspection of High Power Feeder Lines and Connections**
---**Daniel Schneberk**, Robert Maziuk, Boris Soyfer, N. Shashishekhar, and Rahul Alreja, V.J. Technologies, 89 Carlough Road, Bohemia, NY 11716

9:50 AM **Corrosion Monitoring with Tangential Radiography and Limited View Computed Tomography**
---**Uwe Ewert**[1], M. Tschaikner[1], Stefan Hohendorf[1], Carsten Bellon[1], Misty I. Haith[2], Peter Huthwaite[2], and Michael J. S. Lowe[2], [1]BAM-Federal Institute for Materials Research and Testing, Berlin, Germany; [2]Imperial College London, London, United Kingdom

10:10 AM ***Break***

10:30 AM **Modelling Based Radiography for NDE of Subsea Pipelines**
---**Misty I. Haith**[1], Uwe Ewert[2], Stefan Hohendorf[2], Carsten Bellon[2], Andreas Deresch[2], Peter Huthwaite[1], Michael J. S. Lowe[1], and Uwe Zscherpel[2], [1]Imperial College, Department of Mechanical Engineering, London, United Kingdom; [2]BAM Federal Institute for Materials Research and Testing, Berlin, Germany

10:50 AM **An Optical Scanner Model for Computed Radiography Systems**
---**Andreas Schumm**[1], Min Yao[2], Angela Peterzol-Parmentier[3], Valerie Kaftandjian[2], and Philippe Duvauchelle[2], [1]EDF R&D – EDF-Lab les Renardieres 77818 Moret sur Loing, France; [2]INSA Lyon – 25 avenue Jean Capelle 69621 Villeurbanne, France; [2]Areva NDE Solutions – 4 rue Thomas Dumorey, 71100 Chalon-sur-Saône, France

11:10 AM **NDE of Spacecraft Materials Using 3D Compton Backscatter X-Ray Imaging**
---**Eric Burke**, NASA Langley Research Center, Hampton, VA 23681; Victor Grubsky, Volodymyr Romanov, and Keith Shoemaker, Physical Optics Corporation, 1845 W. 205th Street, Torrance, CA 90501

11:30 AM **Scintillating Quantum Dots for Imaging X-rays (SQDIX) for Aircraft Inspection**
---**Eric Burke**[1,] Phillip Williams, and Stan Dehaven, [1]NASA Langley Research Center, Hampton VA 23681

11:50 AM **Application of Dual-Energy X-Ray Techniques for Automated Food Container Inspection**
---**N. Shashishekhar**[1] and D. Veselitza[1], [1]V.J. Technologies, Inc., 89 Carlough Rd, Bohemia, New York 11716

12:10 PM ***Lunch***

8:30 AM

Radiographic Applications in Micro Electronic Industries

---P. Krüger[1], **N. Meyendorf**[1], M. Oppermann[2], P. Sättler[1] and K.-J. Wolter[2], [1]Fraunhofer IKTS-MD, Berlin and Dresden, [2]Technische Universitaet Dresden, Electronics Packaging Lab. (IAVT), Germany

---New concepts in assembly technology boost our daily life in an unknown way. High end semiconductor industry today deals with functional structures down to a few nanometers. ITRS roadmap predicts an ongoing decrqease of the “DRAM half pitch” over the next decade. Packaging of course is not intended to realize pitches at the nanometer scale, but has to face the challenges of integrating such semiconductor devices with smallest pitch and high pin counts into systems. System integration (SiP, SoP, Hetero System Integration etc.) into the third dimension is the only way to reduce the gap between semiconductor level and packaging level interconnection. The described development is mainly driven by communication technology but also other branches like power electronics benefit from the vast progress in integration and assembly technology. The challenge of advanced packaging requires new nondestructive evaluation (NDE) techniques for technology development and production control. In power electronics production the condition monitoring receives a lot of interest to avoid electrical shortcuts, dead solder joints and interface cracking. It is also desired to detect and characterize very small defects like transportation phenomenon or Kirkendall voids. For this purpose imaging technologies with resolutions in the sub-micron range are required. Furthermore the task is not only to identify any impurities on the package surface, but also to look as deep as possible into the package volume. In the case of directly integrated sensor systems for ultralight fibre composite structures of aircrafts, pipelines or wind power plants. Such structure integrated sensor systems for monitoring of complex technical systems must fulfil highest requirements on lifetime and reliability. The stability in device performance is mainly limited by the reliability of the assembly technology, like PCB assembly and soldering. This part of the module is at a very high level of integration not accessible by optical inspection (AOI). Also classical inspection methods like ultrasound testing suffer from the complicated structure of the PCB. Thus, the best tool to investigate such constructions is x-ray inspection. On one hand simple circuits can be inspected using just radiographic images (AXI). However, modern PCBs are three dimensional artworks. Thus only 3D methods can access such structures.

Fig. 1. From left to right: X-ray CT of an USB device, high resolution computer laminography of a BGA and a virtual cross section of TSV-structures using nano-CT.

Our presentation discusses the potentials and the limits of X-ray NDE techniques, illustrated by crack observation in solder joints, evaluation of micro vias in PCBs and interposers and the investigation of solder material composition and other aftermaths of electro migration in solder joints. Applied radiographic methods are X-ray through transmission, multi-energy techniques, laminography, CT and nano-CT. For evaluation examples see figure 1. To complete the main part the gained results of x-ray tests are compared to other NDE methods like ultrasonic and thermal microscopy as well as to the results of destructive tests. Future needs and requirements of NDT methods are derived. Some information on damage induced by the radiation will be presented as well.

9:10 AM

Implementation and Evaluation of Two Helical CT Reconstruction Algorithms in CIVA

---Hussein Banjak[1,2], Marius Costin[1], Caroline Vienne[1], Valérie Kaftandjian[2], [1]CEA, LIST, Département Imagerie et Simulation pour le Contrôle, F-91191 Gif-sur-Yvette, France; [2]LVA, Laboratoire Vibrations Acoustique, INSA-Lyon, F-69621 Villeurbanne, France

---This work presents recent advances achieved in the X-ray CT module of CIVA (the simulation platform for non-destructive testing techniques developed at CEA) and more precisely the integration of helical scanning trajectories and two associated reconstruction algorithms. Previously, only the circular trajectory was used as it is the most common case in practice. As reconstruction algorithms the standard Feldkamp-Davis-Kress (FDK) algorithm is implemented together with two iterative ones adapted for low number of projections but limited to low divergence geometries. When inspecting long objects which are highly anisotropic on a circular scanning geometry, the use of the FDK algorithm creates severe artifacts in the reconstruction. To handle this aspect known as the long-object problem an acquisition on a helical trajectory can be used, similar to medical CT devices. Recently, several analytically exact and quasi-exact inversion formulas for helical cone-beam reconstruction have been proposed. In this work we modified some steps and we implemented two algorithms of filtered-backprojection (FBP) and backprojection-filtration (BPF) approaches for reconstruction on a helical trajectory. These algorithms are fast because of their filtered-backprojection structure and perform an exact reconstruction. Based on these numerical implementations, two plugins for helical reconstruction were integrated in CIVA. In this paper we present a numerical comparison of the two algorithms with the standard FDK algorithm using both noiseless and noisy data. The testing object used to perform our CIVA simulations is a multi-disk phantom which reveals the weaknesses of the standard FDK algorithm.

9:30 AM

Application of Offset-CT Scanning to the Inspection of High Power Feeder Lines and Connections

---**Daniel Schneberk**, Robert Maziuk, Boris Soyfer, N. Shashishekhar, and Rahul Alreja, V.J. Technologies, 89 Carlough Road, Bohemia, NY 11716

---VJT is developing techniques and scanning methods for the in-situ Radiographic and Computed Tomographic inspection techniques for underground high-power feeder cables. The goals for the inspection are to measure the 3D state of the cables and the cable-connections. Recent in-situ Digital Radiographic inspections performed by VJT have demonstrated the value of NDE inspection information for buried power lines. These NDE data have raised further questions as to the exact state of the cables and connections and pointed to the need for more 3D information of the type provided by volumetric CT scanning. VJT is pursuing a three phased approach to address the many issues involved in this type of inspection: 1) develop a high-power feeder-cable test-bed CT scanner, 2) acquire scans on underground feeder pipe that has been removed from service, and 3) from the work in 1) and 2) develop limited-angle CT scanning methods for extending in-situ Digital Radiography to volumetric CT measurements. To this end, VJT has developed and fielded a high-energy test-bed Gantry-type CT scanner (the source and detector move around the object) with a number of important properties. First, the geometry of the gantry-scans can be configured to match the techniques used in the in-situ radiographic inspection. The same X-ray source is employed as in portable Radiographic inspections, a 7.5 MeV Betatron coupled to a Perkin-Elmer Amorphous Silicon detector. Offset-CT scanning is employed as the high-power feeder line assembly is larger than the detector. A description of this scanner and the scan geometry will be presented showing the connection to in-situ radiography. Results from the CT scans of high-power feeder-cable specimens removed from service will be presented with a focus on the inspection potential of volumetric CT data on these assemblies. An evaluation of the scan performance properties of these data compared to the spectrum of life-cycle inspection issues will be presented. Continuing and future work on limited angle CT of these objects will be discussed. The future impact of this type of scanning for better managing aging infrastructure will be assessed.

9:50 AM

Corrosion Monitoring with Tangential Radiography and Limited View Computed Tomography

---**Uwe Ewert**[1], M. Tschaikner[1], Stefan Hohendorf[1], Carsten Bellon[1], Misty I. Haith[2], Peter Huthwaite[2], and Michael J. S. Lowe[2], [1]BAM-Federal Institute for Materials Research and Testing, Berlin, Germany; [2]Imperial College London, London, United Kingdom

---Accurate and reliable detection of pipeline corrosion is required in order to verify integrity of pipelines in the petrochemical industry. The radiographic inspection of corrosion and the measurement of wall thickness loss have been standardized in EN 16407, part 1 and 2: 2014. For thick-walled pipes with large diameters, tangential radiographic inspection can only be applied with high energy radiography. Tangential radiographic inspection is a suitable method to accurately measure the wall thicknesses of pipe walls in reference to comparators. Double wall radiographic inspection with evaluation of the intensity of indications is less accurate for thickness measurements than tangential radiographic inspection and it is not the best choice for the prediction of pipe life. A 7.5 MV betatron was used to penetrate a stepped pipe and a welded test pipe of 3 m length and 327 mm outer diameter, with different artificial corrosion areas in the 24 mm thick steel wall. The radiographs were taken with a 40 x 40 cm^2 digital detector array, which was not large enough to cover the complete pipe diameter after magnification. A C-arm based geometry was tested to evaluate the potential for automated inspection in field. The primary goal was the accurate measurement of wall thickness conforming to the standard. The same geometry was used to explore the ability of a C-arm based scanner in asymmetric mode for computed tomography (CT) measurement, taking projections covering only two thirds of the pipe diameter. The technique was optimized with the modelling software aRTist. A full volume of the pipe was reconstructed and the CT data set was used for reverse engineering, providing a CAD file for further aRTist simulations to explore the technique for subsea inspections which will be discussed in a separate presentation.

10:30 AM

Modelling Based Radiography for NDE of Subsea Pipelines

---**Misty I. Haith**[1], Uwe Ewert[2], Stefan Hohendorf[2], Carsten Bellon[2], Andreas Deresch[2], Peter Huthwaite[1], Michael J. S. Lowe[1], and Uwe Zscherpel[2], [1]Imperial College, Department of Mechanical Engineering, London, United Kingdom; [2]BAM Federal Institute for Materials Research and Testing, Berlin, Germany

---Accurate and reliable detection of subsea pipeline corrosion is required in order to verify integrity of the pipeline. Often a pipeline can be inspected internally by pigging, however where this cannot be applied external examination must be used. Radiography holds a significant advantage over many other NDT methods in that it does not require surface preparation or insulation removal; in addition it is less sensitive to naturally grown external deposits on the pipe surface than other inspection techniques. Subsea radiography often exploits modern digital detectors, and thus has great potential to benefit from the advantages these offer. Identifying the most suitable imaging setups is crucial, both for cost effectiveness and reliable detection and sizing of defects. Standards for radiographic imaging of corrosion (EN 16407) do not currently cover underwater conditions, and as water is highly scattering it can have a significant impact on radiographic image quality: this increases the need to investigate subsea inspection configurations. However, subsea radiography is extremely costly, and extensive experimental data for research is difficult to obtain. This work presents the use of limited experimental measurements to develop a set of calibrated simulation parameters that can then be used for reliable simulation of subsea inspections. The modelling software aRTist is used as the simulation tool, and the calibration is through comparison with experimental images of well characterised samples in a water tank, with matching of image quality parameters such as signal-to-noise ratio, contrast and basic spatial resolution. The presentation addresses the setting up and calibration of the simulation model, and illustrates its use on example inspections. Different setups are compared and the effects of water on image quality parameters quantified.

10:50 AM

An Optical Scanner Model for Computed Radiography Systems

---Andreas Schumm[1], Min Yao[2], Angela Peterzol-Parmentier[3], Valerie Kaftandjian[2] and Philippe Duvauchelle[2], [1]EDF R&D – EDF-Lab les Renardières 77818 Moret sur Loing, France; [2]INSA Lyon -25 avenue Jean Capelle 69621 Villeurbanne, France; [2]Areva NDE Solutions – 4 rue Thomas Dumorey, 71100 Chalon-sur-Saône, France

---Modeling a CR system requires both the simulation of the imaging plate exposure as well as the optical read-out process by a scanning laser, since both aspects have an important impact on the resulting image quality. In particular, the optical scanning process determines the total spatial resolution of the system to a larger extent than the inherent unsharpness of the detector system, due to a finite laser size, optical dispersion within the detection, and the movement of the laser. Since the optical scanning stage is a destructive process which partially erases the image. We present the motivation of our work, an overview of the complete simulation including the IP exposure stage, and elaborate on the Monte Carlo model developed to simulate the propagation of optical light within the imaging plate. The model allows to take a number of influential parameters into account, and the result, which characterizes a given scanner and parameter set, is used in an analytical model in the final application.

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11:10 AM

NDE of Spacecraft Materials Using 3D Compton Backscatter X-Ray Imaging

---Eric Burke, NASA Langley Research Center, Hampton, VA 23681; Victor Grubsky, Volodymyr Romanov, and Keith Shoemaker, Physical Optics Corporation, 1845 W. 205th Street, Torrance, CA 90501

---We present the results of testing of the NDE performance of a Compton Imaging Tomography (CIT) system for single-sided, penetrating 3D inspection, recently developed by Physical Optics Corporation (POC) and delivered to NASA for testing and evaluation. The CIT technology is based on 3D structure mapping by collecting the information on density profiles in multiple object cross sections through hard x-ray Compton backscatter imaging. The individual cross sections are processed and fused together in software, generating a 3D map of the density profile of the object, which can then be analyzed slice-by-slice in x-, y-, or z-directions. The developed CIT scanner is based on a 200-kV x-ray source, flat-panel x-ray detector (FPD), and apodized x-ray imaging optics. The CIT technology is particularly well suited to the NDE of lightweight aerospace materials, such as the thermal protection system (TPS) ceramic and composite materials, micrometeoroid and orbital debris (MMOD) shielding, spacecraft pressure walls, inflatable habitat structures, composite overwrapped pressure vehicles (COPVs), and aluminum honeycomb materials. The current system provides 3D localization of defects and features with field of view 20x12x8 cm and spatial resolution ~2 mm. In this presentation, we review several aerospace NDE applications of the CIT technology, with particular emphasis on the NDE of composites and quality control of TPS. The CIT performance is compared with other common NDE approaches, such as x-ray computed tomography (CT) and ultrasound inspection. Based on the analysis of the testing results, we provide recommendations on which applications can benefit the most from the unique capabilities of this new NDE technology. The CIT system development was funded by the NASA SBIR program. The POC team would like to thank NASA for the support.

11:30 AM

Scintillating Quantum Dots for Imaging X-rays (SQDIX) for Aircraft Inspection

---Eric Burke[1,] Phillip Williams, and Stan Dehaven, [1]NASA Langley Research Center, Hampton VA 23681

---Scintillation is the process currently employed by conventional x-ray detectors to create x-ray images. Scintillating quantum dots or nano-crystals (StQDs) are a novel, nanometer-scale material that upon excitation by x-rays, re-emit the absorbed energy as visible light. StQDs theoretically have higher output efficiency than conventional scintillating materials and are more environmental friendly. This paper will present the characterization of several critical elements in the use of StQDs that have been performed along a path to the use of this technology in wide spread x-ray imaging. Initial work on the SQDIX system has shown great promise to create state-of-the-art sensors using StQDs as a sensor material. In addition, this work also demonstrates a high degree of promise using StQDs in microstructured fiber optics. Using the microstructured fiber as a light guide could greatly increase the capture efficiency a StQDs based imaging sensor.

11:50 AM

Application of Dual-Energy X-Ray Techniques for Automated Food Container Inspection

---N. Shashishekhar[1] and D. Veselitza[1], [1]V.J Technologies, Inc., 89 Carlough Rd, Bohemia, New York 11716

---Manufacturing for food containers often results in small metal particles getting into the containers during the production process. Metal detectors are usually not sensitive enough to detect these metal particles (0.5 mm or lesser), especially when the containers are stacked in large sealed shipping packages; X-ray inspection of these packages provides a viable alternative. This paper presents the results of an investigation into dual-energy X-ray techniques for automated detection of small metal particles in food container packages. The sample packages consist of sealed cardboard boxes containing stacks of food containers: plastic cups for food, and Styrofoam cups for noodles. The primary goal of the investigation was to automatically identify small metal particles down to 0.5 mm diameter in size or less, randomly located within the containers. The multiple container stacks in each box make it virtually impossible to reliably detect the particles with single energy X-ray techniques either visually or with image processing. The stacks get overlaid in the X-ray image and create many indications almost identical in contrast and size to real metal particles. Dual-energy X-ray techniques were investigated and found to result in a clear separation of the metal particles from the food container stack-ups. Automated image analysis of the resulting images provides reliable detection of the small metal particles.

Session 28

SESSION 28
NDE OF CHARACTERIZATION
Eric Lindgren and John Aldrin, Co-Chairpersons
Nicollet D2

8:30 AM **Model-Based Inverse Methods for Sizing Cracks of Varying Shape and Location in Bolt-Holt Eddy Current (BHEC) Inspections**
---**John C. Aldrin**, Computational Tools, Gurnee, IL, 60031; Harold A. Sabbagh, Liming Zhao, Elias Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Mark Keiser, Jennifer Flores-Lamb, and David S. Forsyth, TRI/Austin, Austin, TX 78746; Eric A. Lindgren and Ryan Mooers, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

8:50 AM **Flaw Characterization Using Inversion of Eddy Current Response and the Effect of Filters and Scan Resolution**
---**Erin K. Oneida** and Eric B. Shell, Wyle, Dayton, OH 45440; John C. Aldrin, Computational Tools, Gurnee, IL, 60031; Harold A. Sabbagh, Elias Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Siamack Mazdiyasni and Eric A. Lindgren, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

9:10 AM **Effect of Angular Variations on Split D Differential Eddy Current Probe Response**
---**Ryan Mooers**, Air Force Research Labs, Material State Awareness and Supportability Branch, Wright Patterson Air Force Base, Wright Patterson, OH, 45433; John Aldrin, Computational Tools, Gurnee Il, 60031

9:30 AM **Wavefield Data Analysis to Characterize Angle-Beam Shear Waves Scattered from Crack-Like Defects**
---**Alexander J. Dawson**, Jennifer E. Michaels, Joseph W. Kummer, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

9:50 AM **Root-Cause Estimation of Ultrasonic Scattering Signatures within a Complex Textured Titanium Alloy**
---**James L. Blackshire**[1], Shaun Freed[2], and Jeong K. Na[2], [1]Air Force Research Lab (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]WYLE Laboratories, Beavercreek, OH 45433

10:10 AM ***Break***

10:30 AM **Ultrasound Finite Element Simulation Sensitivity to Anisotropic Titanium Microstructures**
---**Shaun Freed**[2], James L. Blackshire[1], and Jeong K. Na[2]; [1]Air Force Research Lab (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Wyle Laboratories, Dayton, OH 45440

10:50 AM **Progress in Model Development for Eddy Current Response in the Presence of Small Conductivity Changes**
---**Matt Cherry**[1], Shamachary Satish[2], Ryan Mooers[1], and Adam Pilchak[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433; [2]University of Dayton Research Institute, Structural Integrity Division, WPAFB, OH 45433

11:10 AM **Uncertainty Quantification in Modeling and Measuring Components with Resonant Ultrasound Spectroscopy**
---**Eric Biedermann**[2], Leanne Jauriqui[2], John C. Aldrin[3], and Siamack Mazdiyasni[1], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Vibrant Corp., Albuquerque, NM 87113; [3]Computational Tools, Gurnee, IL 60031

12:10 PM ***Lunch***

8:30 AM

Model-Based Inverse Methods for Sizing Surface-Breaking Discontinuities with Eddy Current Probe Variability

---**John C. Aldrin**, Computational Tools, Gurnee, IL, 60031; Eric B. Shell and Erin K. Oneida, Wyle, Dayton, OH 45440; Harold A. Sabbagh, Elias Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Siamack Mazdiyasni and Eric A. Lindgren, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---Prior work on model-based inverse methods with eddy current inspections have demonstrated the capability of sizing surface-breaking cracks in propulsion components with ideal probe conditions. However, there is a critical need for such sizing techniques to be robust to the sometimes widely varying characteristics of eddy current probes used in the field. The objective of this work is to demonstrate and validate signal processing algorithms and model-based inversion techniques to characterize length, depth, width and orientation of surface-breaking cracks using eddy current NDE with varying probe conditions. A series of parametric studies of probe characteristics are presented for a fixed set of well-characterized flaws with varying length, depth, opening width and orientation angle. Results show inversion performance differences between probes with the same design specifications. Several model calibration schemes were also tested in the study. By using a model calibration process that incorporates the matching probe calibration data, better inversion results were achieved to a small degree. This result indicates the potential of leveraging the model calibration process to address differences in the probe. Inversion results were also evaluated for a probe that was selectively controlled for varying probe liftoff, varying tilt in two directions, and orientation using the ECIS system. Certain levels of probe tilt and liftoff were found to degrade the performance of the inversion technique. One promising observation was that all four of these varying probe properties (probe liftoff, probe orientation and probe tilt in two directions) produced different effects on the eddy current response. Thus, there is a need but also a potential to adapt the inversion process based on the probe state from the calibration process. Fundamentally, the key challenge is how to deal with representing the eddy current response over a large number of parameters of varying probe properties and the four parametric flaw characteristics while minimizing the total number of necessary simulations. At the heart of the model, the amplitude and shape of the eddy current response in 2D is quite complex over certain select parameters (i.e. crack length, depth, width and angle) and this requires a good number of parameter levels in order to build a proper surrogate model. Several model probe compensation approaches are under investigation. The most straightforward approach is to simply transform the model in terms of scale and phase based on the best model fit with the calibration data. This approach was implemented but found to only slightly improve inversion performance. A major limitation is that simply morphing the entire surrogate model does not precisely represent the complex nature of the eddy current response across the wide range of flaw sizes, in particular at the center portion of the signal, which leads to inversion error. A second proposed approach is to start with a base surrogate model and then transform it based on an ANOVA-like study for changes in secondary probe parameters and select flaw sizes. This second approach uses a model-based calibration procedure where the probe liftoff, tilt and orientation are inverted following the calibration process. The goal here is to develop more sophisticated transforms of the base surrogate model for secondary parameter changes using limited simulation requirements. Preliminarily results and computational requirements for this approach are presented in the paper.

8:50 AM

Flaw Characterization Using Inversion of Eddy Current Response and the Effect of Filters and Scan Resolution

---**Erin K. Oneida** and Eric B. Shell, Wyle, Dayton, OH 45440; John C. Aldrin, Computational Tools, Gurnee, IL, 60031; Harold A. Sabbagh, Elias Sabbagh, and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Siamack Mazdiyasni and Eric A. Lindgren, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---The objective of this work is to determine the effect of filters and scan resolution on the sizing accuracy of surface defects. Prior work [1, 2] has demonstrated the capability of applying inverse methods to unfiltered, high-fidelity, automated eddy current data. This has shown advantages over a simple amplitude-based analysis of the data. However, to apply this approach to data collected using standard depot inspection settings, the algorithms must be validated on data that is similar in form. Efforts to apply a range of inspection filters and test the resultant effect on inversion robustness and accuracy will be described. In order to handle data sets with a high bandpass filter applied, new data registration algorithms must be developed that are robust for asymmetric signal response data. A few potential options were developed and run against a set of flaw signals with various filters applied. This flaw set was chosen to represent challenging cases that span the range of expected response shapes. In addition to a data registration effect, the signal shape and inversion are dependent on knowing and accounting for the applied filter. Two options were investigated to handle filtered data during inversion. One option is to apply the same filtering to the forward model data set prior to inversion. This option, while straight-forward, is computationally intensive since a separate processing of the forward model set is required for each applied filter. Alternatively, post-processing can be applied to the flaw signal to effectively remove or minimize the effect of the filter. One such option being investigated is to apply a Wiener deconvolution to the data set. For filters that only marginally cut into the frequency content of the flaw, the original signal shape can be adequately recovered. However, there will never be full recovery of the information from the lower frequencies, potentially resulting in characterization errors during the inversion process.

References:

1. Aldrin, J. C., Sabbagh, H. A., Annis, C., Shell, E. B., Knopp, J., and Lindgren, E. A., "Assessing Inversion Performance and Uncertainty in Eddy Current Crack Characterization Applications", Review of Progress in QNDE, Vol. 34, AIP, 1650, p. 1873, (2015).
2. Shell, E. B., Aldrin, J. C., Sabbagh, H. A., Sabbagh, E. H., Murphy, R. K., Mazdiyasni, S., and Lindgren, E. A., "Demonstration of Model-Based Inversion of Electromagnetic Signals for Crack Characterization," Review of Progress in QNDE, Vol. 34, AIP, 1650, p. 484, (2015).

9:10 AM

Effect of Angular Variations on Split D Differential Eddy Current Probe Response

---**Ryan Mooers**, Air Force Research Labs, Material State Awareness and Supportability Branch, Wright Patterson Air Force Base, Wright Patterson, OH, 45433; John Aldrin, Computational Tools, Gurnee Il, 60031

---Over the past few years a series of models have been developed, tested, and validated for numerous differential eddy current probe configurations. These probes have ranged in complexity from simple circular air cored coils to more complex ferrite cored D shaped coils. In addition, the design complexity has ranged from pure differential coils to more complex reflection differential designs. Additional complexities such as angular variations in the probe assembly were recently considered; however, the analysis was limited to qualitative trends in the response. This study builds on recent realistic probe modeling work but will incorporate a more rigorous analysis of how angular variation affects the response of the probe. As opposed to the previous validation exercises, this study will consider rotations around all three axes, unlike previous version which focused on rotation in the XZ plane as seen in Figure 1. A new validation study will be performed to determine if the inclusion of other angular variations increases the agreement between experimental data and model simulations. Furthermore, a sensitivity analysis will be completed to determine which of the angles produce the greatest change in terms of magnitude and shape of the probe response. Details about the experimental setup, data collection and model construction will be given. In addition, details about the quantitative analysis methods for the sensitivity study will be discussed. The results of this paper on both validation agreement and angular sensitivity will provide insight on the effect of probe variability on detection and sizing performance and may provide guidance to improve eddy current calibration procedures and overall probe design optimization

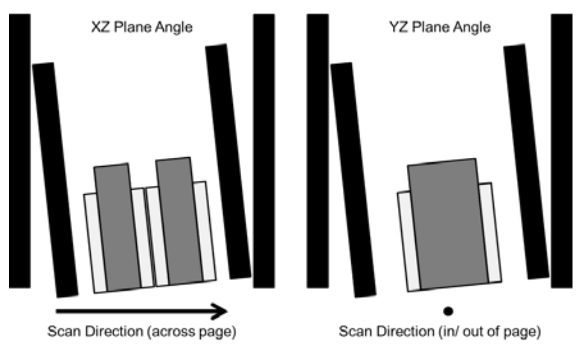


Figure 1. Description of angular variation included in previous modeling efforts.

Reference:

1. R.D. Mooers, J.C. Aldrin, and J.S. Knopp, “Realistic Split D Model Validation,” to be published in *Review of Progress in QNDE,* edited by D.O. Thompson and D.E. Chimenti, (AIP, 2014)

9:30 AM

Wavefield Data Analysis to Characterize Angle-Beam Shear Waves Scattered from Crack-Like Defects

---Alexander J. Dawson, Jennifer E. Michaels, Joseph W. Kummer, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---Ultrasonic wavefield imaging, which refers to the measurement of waveforms over a 2-D rectilinear grid resulting from a fixed source, has been used to study wave propagation for a variety of applications, primarily utilizing guided waves. Wavefield methods have not been generally applied to angle-beam bulk wave propagation in plates for which the wavelength is much smaller than the thickness. Analysis methods developed for guided waves can be applied, but additional challenges arise due to the nature of angle-beam propagation in plates; i.e., the fact that there are multiple reflections between the plate surfaces. Described here are the results of a study of shear wave angle-beam propagation and scattering in plates using wavefield imaging. This topic is of interest because angle-beam techniques are one of the preferred methods of ultrasonic nondestructive evaluation used in industry, and such studies can improve the reliability of data interpretation and serve as a powerful means of model validation. First, results from a 2-D finite element model are presented that show a cross-sectional view of angle-beam wave propagation, and data from the top surface is compared to experimental measurements. The model is also used to gain insight into the generation of the different wave types observed in experimental data. Then, scattering from back surface corner notches of different sizes emanating from a through-hole are considered. Wavefield data are measured in a rectangular region centered on the through-hole at a fine spatial sampling increment. The framework for analysis of these angle-beam wavefields utilizes baseline subtraction to isolate scattered waves from full wavefield data followed by analysis of the residual wavefields. Finally, results are presented that clearly show the effect of the notch size on the scattering behavior.**---**This work is funded by the Air Force Research Laboratory under Contract Number FA8650- 10-D-5210 (Dr. Eric Lindgren, Program Manager).

9:50 AM

Root-Cause Estimation of Ultrasonic Scattering Signatures within a Complex Textured Titanium Alloy

---**James L. Blackshire**[1], Shaun Freed[2], and Jeong K. Na[2], [1]Air Force Research Lab (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]WYLE Laboratories, Beavercreek, OH 45433

---The nondestructive detection of anomalies within modern polycrystalline aerospace materials has been an area of intense research in the past several decades, and continues to be an area of growth in recent years. Titanium alloys in particular have become a critical material system used in modern turbine engine applications, where an evaluation of the local microstructure properties of engine disk/blade components is desired for performance and remaining life assessments. Past research and current methods are often limited to studying and estimating ensemble material properties or detecting localized voids, inclusions, or damage features within the component. Recent advances in computational NDE and material science methods are providing new and unprecedented access to heterogeneous material properties, which is permitting microstructure-sensing interactions to be studied in detail. In the present research activity, Integrated Computational Materials Engineering (ICME) methods and tools are being utilized to gain a comprehensive understanding of root-cause ultrasonic signatures occurring in a textured titanium aerospace material. A combination of destructive, nondestructive, and computational methods are being combined within the ICME framework to collect, holistically integrate, and study ultrasonic complex scattering processes in realistic 2-dimensional and 3-dimensional representations of the microstructure properties. Progress towards validating the computational sensing methods are discussed, along with insight into scattering processes occurring within the bulk microstructure and how they manifest in pulse-echo immersion ultrasound measurements.

10:30 AM

Ultrasound Finite Element Simulation Sensitivity to Anisotropic Titanium Microstructures
---**Shaun Freed**[2], James L. Blackshire[1], and Jeong K. Na[2]; [1]Air Force Research Lab (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Wyle Laboratories, Dayton, OH 45440

---Analytical wave models are inadequate to describe complex metallic microstructure interactions especially for anisotropic property variations and through geometric features smaller than the wavelength. In contrast, finite element ultrasound simulations inherently capture microstructure influences due to their reliance on material definitions rather than wave descriptions. To better quantify when inhomogeneity effects on ultrasonic wave parameters become significant, a finite element modeling case study has been performed to investigate the influence of anisotropic titanium grain structures. A parameterized model has been developed utilizing a series of anisotropic spheres within a bulk material. The resulting wave parameters are studied as a function of wavelength to feature size ratio and also the feature to bulk anisotropic orientation mismatch angle.---This work is funded by the U.S. Air Force Research Lab (AFRL/RXCA).

10:50 AM

Progress in Model Development for Eddy Current Response in the Presence of Small Conductivity Changes

---**Matt Cherry**[1], Shamachary Sathish[2], Ryan Mooers[1], and Adam Pilchak[1], [1]Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433; [2]University of Dayton Research Institute, Structural Integrity Division, WPAFB, OH 45433

---In previous work [1], a model was developed to solve for the response of an eddy current probe in the presence of small changes in conductivity. The model relied on a Bourne-like approximation for the transmitted electric field, and when compared with experimental measurements, was found to agree qualitatively. No theoretical justification for the model was given in the work, and the link between impedance of a coil and the change in conductivity was primarily based on averaging. In this presentation, a new model will be shown which starts from Maxwell's equations and eventually develops a theoretical link between the small conductivity changes and the impedance change of the coil. This model uses a Bourn approximation which simplifies the solution to a numerical integral over a grid of known conductivity changes. The limitations of the model and the relation to previous developments will be discussed, and new experimental data will be presented that shows further issues in implementation. The talk will then focus on how this model can be used in the context of uncertainty propagation in eddy current testing of inhomogeneous anisotropic media. Examples of the implementation in the context of digital design of materials will be shown.

References:

1. Cherry, M. R., Sathish, S., Pilchak, A. L., Cherry, A. J., & Blodgett, M. P. (2014, February). Characterization of microstructure with low frequency electromagnetic techniques. In *40th Annual Review of Progress in Quantitative Nondestructive Evaluation: Incorporating the 10th International Conference on Barkhausen Noise and Micromagnetic Testing* (Vol. 1581, No. 1, pp. 1456-1462). AIP Publishing.

11:10 AM

Uncertainty Quantification in Modeling and Measuring Components with Resonant Ultrasound Spectroscopy

---**Eric Biedermann**[2], Leanne Jauriqui[2], John C. Aldrin[3], and Siamack Mazdiyasni[1], [1]Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433; [2]Vibrant Corp., Albuquerque, NM 87113; [3]Computational Tools, Gurnee, IL 60031

---Resonance Ultrasound Spectroscopy (RUS) is a nondestructive evaluation method which can be used to quantify the elastic properties of a wide range of materials by measuring their resonance spectra. Prior work on gas turbine airfoils exposed to high temperature and stress has shown that RUS is capable of measuring corresponding shifts in frequency peaks. Recent work has enhanced developed forward and inverse modeling capabilities for RUS. Forward models predict the effect of various material states and defect conditions on component resonance frequencies. Inverse models use measured resonance frequencies as an input, and evaluate properties characterizing the component material state. Accurate forward and inverse modeling for RUS requires a proper accounting of the propagation of uncertainty due to both model and measurement sources. A process for quantifying the propagation of uncertainty in RUS frequency results for models and measurements was developed. Sources of uncertainty were identified for forward model parameters, forward model material property and geometry inputs, inverse model parameters, and physical RUS measurements. Both epistemic and aleatory sources of uncertainty were evaluated. RUS model parametric studies were then conducted for simple geometry samples to determine the sensitivity of RUS frequencies to the various sources of uncertainty. The results of these parametric studies were used to calculate uncertainty bounds associated with each source. Uncertainty bounds were then compared to assess the relative impact of the various sources of uncertainty, and mitigations were identified. The elastic material property inputs for forward models, such as Young's Modulus, were found to be the most significant source of uncertainty in these studies. The ranges of variation for material property inputs used for these studies were set by published literature, which often used values on the order of +/-5% for material values. Tightening this range had the biggest overall impact on RUS uncertainty propagation. Comprehensive studies were also performed investigating the complex relationship between model accuracy, frequency selection and inverse model parameters on inversion performance and uncertainty bound. The goal of this work is to develop a process for uncertainty quantification that can be adapted to a broad range of components or materials including more complex geometries and grain structures.

Session 29

SESSION 29
NONLINEAR ULTRASONICS
Katie Matlack and Larry Jacobs, Co-Chairpersons
Nicollet D3

8:30 AM **Quantitative Comparison of Laser and Air-Coupled Nonlinear Ultrasonics in Surface Wave Measurements**
---**David Torello**[1], Jin-Yeon Kim[2], Jianmin Qu[3], and Laurance J. Jacobs[1,2], [1]G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332; [2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; [3]Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208

8:50 AM **Acoustic Nonlinearity Parameters for Transversely Isotropic Polycrystalline Materials**
---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, Lincoln NE 68588

9:10 AM **A Micromechanics Model for the Acoustic Nonlinearity Parameter in Solids with Distributed Microcracks**
---Youxuan Zhao[1,2], Yanjun Qiu[1], **Laurence J. Jacobs**[3], and Jianmin Qu[1]; [1]School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China; [2]Department of Civil and Environmental Engienering, Department of Mechanical Engineering, Northwestern University, Evanston, IL 60208; [3]College of Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

9:30 AM **Nonlinear Ultrasonic Imaging of Closed Cracks in a Coarse Grained Stainless Steel by Global Preheating and Local Cooling**
---**Yoshikazu Ohara**, Koji Takahashi, Yoshihiro Ino, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, 980-8579, Japan

9:50 AM **Rapid and Exhaustive Damage Imaging in Composite Plates without Contact Using Air-Coupled Nonlinear Elastic Wave Spectroscopy**
---**Marcel C. Remillieux**[1], Lukasz Pieczonka[2], Pierre-Yves Le Bas[1], T. J. Ulrich[1], and Brian E. Anderson[1], [1]Geophysics Group (EES-17), MS: D446, Los Alamos National Laaboratory, Los Alamos, New Mexico 87545; [1]Department of Robotics and Mechatronics, AGH University of Science and Technology, Al. A. Mickiewicza 30, 30-059 Krakow, Poland

10:10 AM ***Break***

10:30 AM **Analytical and Numerical Modeling of Non-Collinear Shear Wave Mixing at an Imperfect Interface**
---**Ziyin Zhang**[1], Peter B. Nagy[1], and Waled Hassan[2], [1]Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221; [2]Rolls-Royce Corporation, Indianapolis, IN 46225

10:50 AM **Parametric Analysis of Ultrasonic Wave Mixing**
---**Jack Potter**, Jon Alston, and Anthony Croxford, University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom

11:10 AM **Enhanced Nonlinear Inspection of Diffusion Bonded Interfaces Using Reflected Non-Collinear Ultrasonic Wave Mixing**
---Ziyin Zhang,[1] Peter B. Nagy,[1] and **Waled Hassan**[2], [1]Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221; [2]Rolls-Royce Corporation, Indianapolis, IN 46225

11:30 AM **On the Feasibility of Nonlinear Assessment of Fatigue Damage in Hardened IN718 Specimens Based on Non-Collinear Shear Wave Mixing**
---Ziyin Zhang[1], **Peter B. Nagy**[1], and Waled Hassan[2], [1]University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221; [2]Rolls-Royce Corporation, Indianapolis, IN 46225

11:50 PM **OPEN**

12:10 PM ***Lunch***

8:30 AM

Quantitative Comparison of Laser and Air-Coupled Nonlinear Ultrasonics in Surface Wave Measurements

---**David Torello**[1], Jin-Yeon Kim[2], Jianmin Qu[3], and Laurence J. Jacobs[1,2]; [1]G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332; [2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332; [3]Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL, 60208

---Air-coupled piezoelectric transducers provide the repeatability and ease of use provided by non-contact detection combined with the sensitivity of piezoelectric materials. This makes them a particularly attractive option for nonlinear surface wave ultrasonic measurements, where contact conditions have a substantial impact on signal quality and the received harmonic signals are often low in amplitude and require sensitive receivers. Up to this point, air-coupled transducers have been successfully employed to make measurements of the relative nonlinearity parameter in a variety of specimens, but absolute values of the nonlinear parameter have thus far been elusive because of the difficulty of calibrating these devices. In this work, a combination of air-coupled transducers and laser interferometry is employed to model the propagation of signals from the sample to the face of the air-coupled receiver in surface wave measurements, and the differences between the two methods are explored quantitatively. Additionally, the strengths and weaknesses of both methods are considered and a framework for absolute nonlinearity parameter measurements with air-coupled transducers is evaluated.

8:50 AM

Acoustic Nonlinearity Parameters for Transversely Isotropic Polycrystalline Materials

---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, Lincoln NE 68588

---Modern manufacturing processes are enabling materials to be created with customizable microstructures to allow for optimal material properties catered toward their intended use. Such processes often desire the material properties to be textured or anisotropic. For example, the creation of a material with heightened strength along certain directions is often desirable. This additional microstructural complexity presents new challenges for ultrasonic and material modeling. For nonlinear ultrasonics, previous modeling has focused on relating harmonic amplitudes to relative changes in material damage. Few theoretical models have attempted to describe the acoustic nonlinearity of materials during the period after manufacturing and prior to being placed into their intended use environment. During this period, harmonic measurements could be used to confirm the material has the intended microstructural properties along with establishing a damage-free baseline. This presentation gives theoretical estimates of these measurements. The presented model defines the quadratic nonlinearity of a polycrystalline material with a microstructure containing elastic anisotropy. The anisotropy causes the second-harmonic amplitude of a fundamental longitudinal wave to be dependent on the propagation direction as seen in Fig. 1(a). Furthermore, the anisotropy causes second-harmonics to be generated from an input fundamental shear wave for certain propagation directions as seen in Fig. 1(b). The observation of shear wave harmonics may be used as a tool to quantify the degree of material anisotropy. These estimates provide an approximation of the damage-free baseline and could be used in conjunction with measurements to estimate absolute levels of material damage.

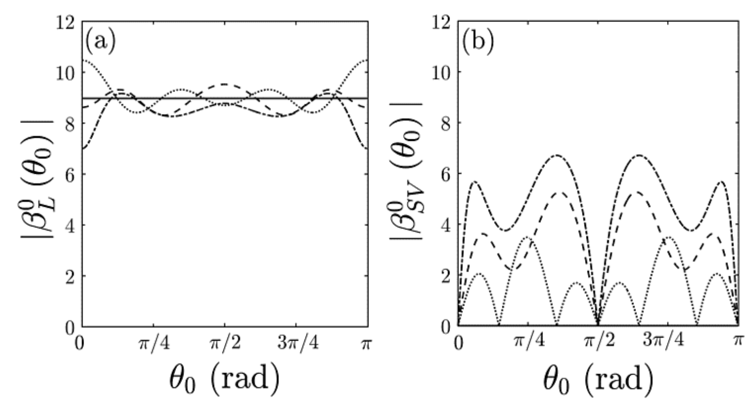


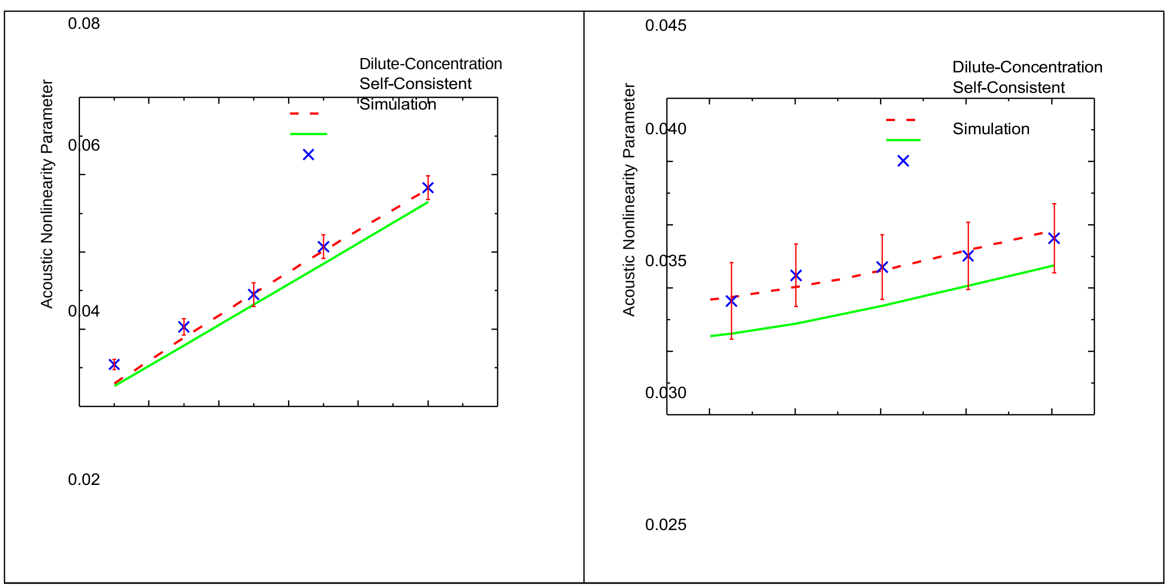
Figure 1. Theoretical quadratic nonlinearity parameters associated with a fundamental longitudinal wave (a) or transverse wave (b) in iron, which has texture leading to elastic anisotropy. The angle defines the propagation direction with respect to the strong texture direction. The dashed lines represent three different realistic texture cases and the solid line represents the isotropic or untextured case.

9:10 AM

A Micromechanics Model for the Acoustic Nonlinearity Parameter in Solids with Distributed Microcracks

---Youxuan Zhao[1,2], Yanjun Qiu[1], Laurence J. Jacobs[3], and **Jianmin Qu**[2]; [1]School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China; [2]Department of Civil and Environmental Engineering, Department of Mechanical Engineering Northwestern University, Evanston, IL 60208; [3]College of Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

---As a longitudinal wave propagates through an elastic solid with distributed microcracks, higher order harmonics might be generated due to several sources of nonlinearity in the cracked solid. One of them is crack face contact. During the tensile cycles of the wave motion, the cracks are open and the crack faces are traction-free. During the compressive cycles of the wave motion, the cracks are closed and the crack faces are in contact. Such contact may also be frictional because of crack face roughness. This paper develops a model that relates the crack density to the acoustic nonlinearity parameter caused by such frictional crack face contact in a solid with distributed microcracks. The model is based on a micromechanics homogenization of the cracked solid under dynamic loading. It is shown that the acoustic nonlinearity parameter is proportional to the crack density, and is frequency-dependent.
Unlike the second harmonic generated by dislocations, the amplitude of the second harmonic due to crack face contact is proportional to the amplitude of the fundamental frequency. To validate the micromechanics model, the finite element method is used to simulate wave propagation in solid with randomly distributed microcracks. The Coulombs friction law is used to model crack face contact. The simulation results agree well with the model predictions.---The work was supported in part by the US National Science Foundation through CMMI-1363221 and in part by the US Department of Energy's Nuclear Energy University Program through Standard Research Contracts 00126931 and 00127346.



9:30 AM

Nonlinear Ultrasonic Imaging of Closed Cracks in a Coarse Grained Stainless Steel by Global Preheating and Local Cooling

---**Yoshikazu Ohara**, Koji Takahashi, Yoshihiro Ino, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, 980-8579, Japan

---The inspection of coarse grained material is highly demanded in aged structures. In particular, the detection of closed crack is the most challenging subject. Thus far, as a method of measuring closed crack depth, we have developed a closed crack depth measurement method, which combines a practical, temporarily crack opening method, global preheating and local cooling (GPLC) [1] and linear phased array (PA) (Figs. 1(a) and 1(b)). To enhance the selectivity of closed cracks for linear scatterers such as coarse grains, we have proposed load difference phased array (LDPA) (Fig. 1(c)), which is based on the subtraction between PA images at different loads (thermal stress). Those methods were demonstrated in an aluminum alloy (A7075) with a closed fatigue cracks. However, it has yet to be verified in coarse grained material. In this study, we applied GPLC to coarse grained stainless steel specimen with a closed fatigue crack. Before applying GPLC, the crack was not imaged by PA (Fig. 2(a)). This shows that the crack was tightly closed. Then, by applying GPLC, the crack was imaged by PA (Fig. 2(b)). However, it was difficult to identify the crack tip because the signal-to-noise ratio was not high due to the strong linear scattering at coarse grains. Therefore, we applied LDPA to the PA images. As a result, we succeeded in accurately measuring the closed crack depth (Fig. 2(c)). This, we demonstrated that the combination of GPLC and LDPA is very useful in measuring closed-crack depth in coarse grained structures.

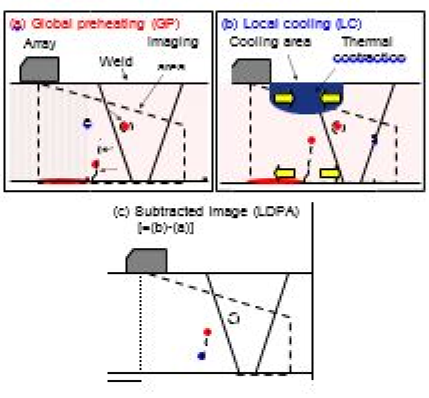


Figure 1. GPLC and LDPA

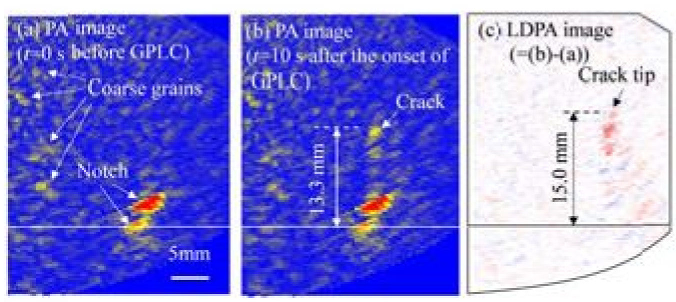


Figure 2. Imaging results of closed fatigue crack in coarse grained stainless steel specimen

References:

1. Y. Ohara, K. Takahashi, S. Murai, and K. Yamanaka, "High-Selectivity Imaging of Closed Cracks Using Elastic Waves with Thermal Stress Induced by Global Preheating and Local Cooling," Appl. Phys. Lett., 103, 031917-1-5 (2013).
2. Y. Ohara, S. Horinouchi, M. Hashimoto, Y. Shintaku, and K. Yamanaka, "Nonlinear Ultrasonic Imaging Method for Closed Cracks Using Subtraction of Responses at Different External Loads," Ultrasonics, 51, 661-666 (2011).

9:50 AM

Rapid and Exhaustive Damage Imaging in Composite Plates without Contact Using Air-Coupled Nonlinear Elastic Wave Spectroscopy

---**Marcel C. Remillieux**[1], Łukasz Pieczonka[2], Pierre-Yves Le Bas[1], T.J. Ulrich[1], and Brian E. Anderson[1], [1]Geophysics Group (EES-17), MS: D446, Los Alamos National Laboratory, Los Alamos, New Mexico 87545; [2]Department of Robotics and Mechatronics, AGH University of Science and Technology, Al. A. Mickiewicza 30, 30-059 Krakow, Poland

---We present the first set of experiments in which air-coupled ultrasonic emission is used to image simultaneously a delamination and a crack in a laminated composite. Such experiments have been limited thus far by the impedance mismatch of nearly five orders of magnitude between the air and an elastic solid. This limitation was overcome by designing an ultrasonic source based on the principle of time reversal and the acoustic black-hole effect (Fig. 1a). This novel device is capable of generating a focused elastic wave field in the composite plate with an amplitude sufficiently large to allow the use of nonlinear elastic wave spectroscopy. The setup of a typical experiment conducted with this source is shown in Fig. 1b. The source can be used to focus energy efficiently into the plate with a stand-off distance of up to 6cm. The image of the damaged area obtained with the proposed apparatus and signal processing technique (Fig. 1c) reveal the same features as with vibro-thermography (Fig. 1d) and more features than with a C-scan, but remove the need to be in direct contact with the composite, thus reducing the test time by orders of magnitude.---We gratefully acknowledge the support of the U.S. Department of Energy through the LANL/LDRD Program and the Fuel Cycle R&D, Used Fuel Disposition (Storage) campaign. The visit of Dr. Pieczonka was supported by the Foundation for Polish Science (FNP) within the scope of the WELCOME Program - project no. 2010-3/2.

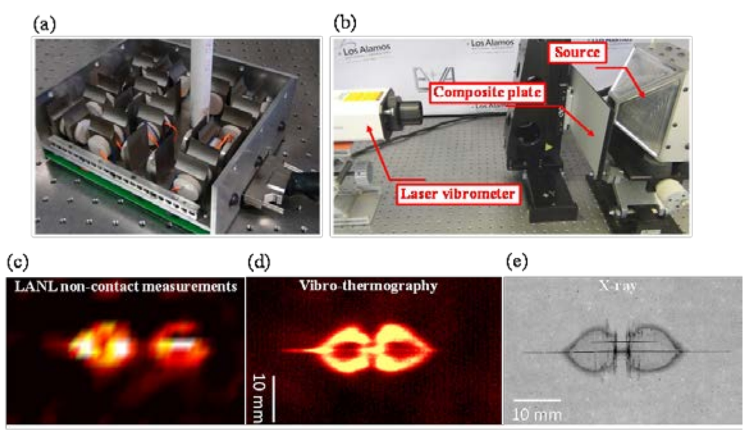


Figure 1. Non-contact imaging of a delamination and crack in a composite plate. (a) Interior of the non-contact source showing the arrangement of the 32 transducers. (b) Experimental setup for the non-contact excitation and sensing. (c)-(e) Images of the defect using the non-contact source combined with nonlinear elastic spectroscopy, vibro-thermography, and X-ray.

10:30 AM

Analytical and Numerical Modeling of Non-Collinear Shear Wave Mixing at an Imperfect Interface

---Ziyin Zhang[1], Peter B. Nagy[1], and Waled Hassan[2], [1]Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221; [2]Rolls-Royce Corporation, Indianapolis, IN 46225

---Non-collinear shear wave mixing at an imperfect interface between two solids can be exploited for nonlinear ultrasonic assessment of bond quality. In this study we developed two analytical models for nonlinear imperfect interfaces. The first model uses a nonlinear interphase layer of finite thickness, while the second model relies on a finite nonlinear interfacial stiffness representation to simulate an interface imperfection of negligible thickness. Both models were used to study non-collinear shear wave mixing using analytical methods. These analytical predictions were then numerically verified using COMSOL finite element simulations for the case of nonlinear interfaces between two hyperelastic half-spaces. Both models can accurately predict the excess nonlinearity caused by the imperfect interface based on the strength of the reflected and transmitted mixed longitudinal waves.

10:50 AM

Parametric Analysis of Ultrasonic Wave Mixing

---**Jack Potter**, Jon Alston, and Anthony Croxford, University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom

---Treatment of nonlinear wave mixing typically restricts analysis to so called resonant criteria, a parametric operating point where interaction through the whole intersecting volume contributes constructively in the far field. Analysis of the full, non-resonant, interaction angle-frequency ratio parameter space, an example of which is shown in Fig. 1, yields some interesting features. Firstly, the influence of elastic nonlinearity perturbs the peak response from the resonant solution. Dynamic range, which is of crucial importance in nonlinear acoustics, may therefore me maximised by operating away from the intuitive resonant solutions. Furthermore, changes in both linear and nonlinear material properties local to the interaction volume modify the shape of the parameter space. This presents the possibility for better material characterisation through analysis of the shape of this surface in addition to its peak amplitude. Since it can be shown that the normalised shape of this parameter space is independent on incident amplitude, such analysis has the potential to be more robust than absolute amplitude alone.

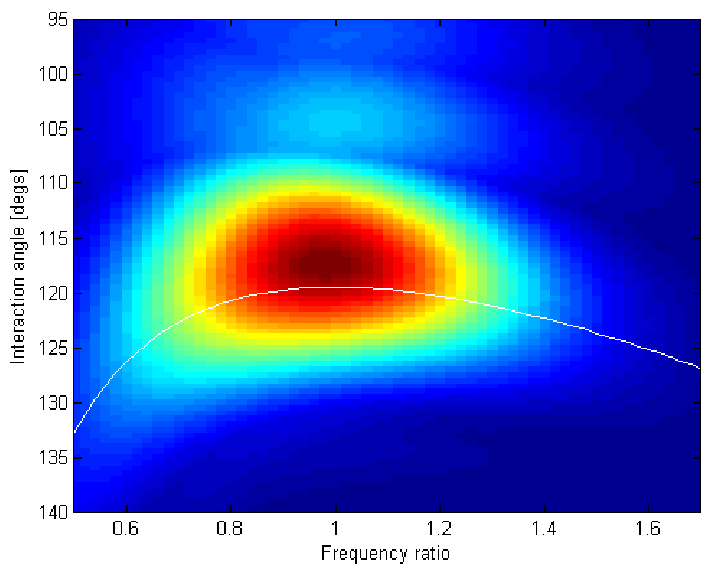


Figure 1. Theoretical non-collinear parameter space. Resonant solution shown by white line.

11:10 AM

Enhanced Nonlinear Inspection of Diffusion Bonded Interfaces Using Reflected Non-Collinear Ultrasonic Wave Mixing

---Ziyin Zhang,[1] Peter B. Nagy,[1] and **Waled Hassan**[2], [1]Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221; [2]Rolls-Royce Corporation, Indianapolis, IN 46225

---Ultrasonic wave mixing has shown promising potential for assessing otherwise hidden subtle imperfections in imperfect diffusion bonds between Ti-6Al-4V components. When interrogating a diffusion bonded specimen using non-collinear shear wave mixing, both bulk and interface nonlinearity will contribute to the transmitted nonlinear signal. Although a recent study has shown that changing the transducer alignment can suppress the intrinsic nonlinearity of the surrounding material to some extent so that the interface nonlinearity could be detected more selectively, it is still difficult to distinguish different levels of bond qualities based on the detected signal only. Analytical and numerical studies showed that a nonlinear interface would generate the same amount of nonlinear displacement in the reflected and transmitted fields. In this study, we used the reflected nonlinear interface signature to characterize diffusion bonded interfaces. Our results indicate that it is indeed better to use the reflected nonlinear interface signature to assess the bond quality, which is in agreement with our previous analytical and numerical predictions. However, the observed random phase of the reflected signature indicates that existing nonlinear interface models are insufficient for accurately describing the nonlinear interaction of shear incident waves with high-quality diffusion bonded interfaces.

11:30 AM

On the Feasibility of Nonlinear Assessment of Fatigue Damage in Hardened IN718 Specimens Based on Non-Collinear Shear Wave Mixing

---Ziyin Zhang,[1] **Peter B. Nagy**,[1] and Waled Hassan[2], [1]University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221; [2]Rolls-Royce Corporation, Indianapolis, IN 46225

---Recent studies have shown that various ultrasonic wave mixing techniques can be exploited for assessing the nonlinearity of both intact and damaged materials. It has been reported that one particular type of ultrasonic wave mixing, non-collinear shear wave mixing, is sensitive to the excess nonlinearity caused by plastic deformation and low-cycle fatigue in Al2014-T4 aluminum alloy. In this study we investigated the feasibility of using the same non-collinear shear wave mixing technique to detect plastic deformation and fatigue damage in fully hardened IN718 engine alloy specimens. We implemented numerous technical improvements over the earlier developed non-collinear shear wave mixing system to improve its detection sensitivity and image resolution. In spite of these enhancements, we found that in fully hardened IN718 this technique is sensitive only to plastic deformation and, to a much lesser degree, to highly accelerated low-cycle fatigue, but it is not sensitive to either typical low-cycle fatigue or high-cycle fatigue. These observations highlight a potential deficiency in our current understanding of nonlinear material-wave interaction and suggest that further research is needed to explain why certain classes of dislocation networks remain hidden from this type of inspection.

Session 30

SESSION 30
NUCLEAR
Bill Glass and Andrew Gavens, Chairpersons
Nicollet D1

8:30 AM **Mitigating the Effects of Surface Morphology Changes During Ultrasonic Wall Thickness Monitoring**
---**Frederic B Cegla** and Attila Gajdacsi, Imperial College London, NDE Group, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

8:50 AM **NDE of Power Station Creep Weld Failures Using a PD Technique**
---**Joseph Corcoran**, Imperial College, 318 City & Guilds Building, Exhibition Road, London SW7 2AZ, United Kingdom

9:10 AM **Conformable Eddy Current Array Delivery**
---**Rahul Summan**[1], Gareth Pierce[1], Charles Macleod[1], Gordon Dobie[1], Gary Bolton[2], Angélique Raude[3], Colombe Dalpé[3], and Johannes Braumann[4], [1]Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; [2]National Nuclear Laboratory, Chadwick House, Warrington Road, Birchwood Park, Warrington, WA3 6AE, United Kingdom; [3]Eddyfi Europe SAS, 110 Allée des Lilas, Les Fenières, Parc Industriel de la Plaine de l'Ain, 01150, Saint-Vulbas, France; [4]Association for Robots in Architecture, Vienna University of Technology, Karlsplatz 13, 1040 Wien, Austria

9:30 AM **Experimental Validation of Ultrasonic NDE Simulation Software**
---G. Dib, **M. R. Larche**, A. A. Diaz, S. L. Crawford, M. S. Prowant, and M. T. Anderson, Pacific Northwest National Laboratory, Richland, WA 99354

9:50 AM **Development of Under-Sodium Viewing Technology for In-Service Inspection of Liquid Metal Fast Reactors**
---**M. R. Larche**, D. L. Baldwin, M. K. Edwards, R. A. Mathews, T. S. Hartman, M. S. Prowant, and A. A. Diaz, Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352

10:10 AM ***Break***

10:30 AM **Modeling Ultrasonic Transducers for Operation in Liquid Metal and Molten Salt Small Modular Reactors (SMR)**
---**Prathamesh N. Bilgunde** and Leonard J. Bond, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

10:50 AM **WITHDRAWN - PARENT Round Robin Blind Test**
---**Ryan Meyer**, Pacific Northwest National Laboratory, 902 Battelle Blvd., P. O. Box 999, MSIN K5-25, Richland, WA 99352

11:10 AM **Assessment of Key Indicators of Aging Cables in Nuclear Power Plants – Interim Status**
---**S. W. Glass**, P. Ramuhalli, L. S. Fifield, M. S. Prowant, G. Dib, J. R. Tedeschi, J. D. Suter, A. M. Jones, M. S. Good, and A. F. Pardini, Pacific Northwest National Laboratory, Richland WA 99352

11:30 AM **Limitations of Eddy Current Testing in a Fast Reactor Environment**
---**John Bowler**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:50 PM **OPEN**

12:10 PM ***Lunch***

8:30 AM

Mitigating the Effects of Surface Morphology Changes During Ultrasonic Wall Thickness Monitoring

---**Frederic B Cegla** and Attila Gajdacsi, Imperial College London, NDE Group, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Ultrasonic wall thickness monitoring using permanently installed sensors has become a tool to monitor pipe wall thicknesses online and during plant operation. The repeatability of measurements with permanently installed transducers is excellent and can be in the nanometer range. It has, however, also been shown that the measured wall thickness is dependent on surface morphology and that when there are changes in surface morphology the monitored thickness trends can be affected. With an adaptive cross correlation approach, this effect can be successfully muted. However, under some surface morphology change conditions, this can also lead to inaccuracies. Here, an approach to detect when surface morphology changes can influence trend accuracies is presented. This method requires the combination of measurements from several sensors that independently sample an area where the same wall loss mechanism is assumed to occur. Simulation results for the effectiveness of the technique are presented.

8:50 AM

NDE of Power Station Creep Weld Failures Using a PD Technique

---**Joseph Corcoran**, Imperial College, 318 City & Guilds Building, Exhibition Road, London SW7 2AZ, United Kingdom

---Creep failure of pressurised power station components is known to be a particular concern at both seam and girth welds. EPRI documented 27 incidences of seam weld failure and major cracking by 2003 [1] but it is known that this number continues to rise [2]. The most well-known are the 1985 Mohave Power Station disaster which caused 6 fatalities and the Monroe catastrophic failure in 1986 [1]. Concern about catastrophic failure in girth welds however is minimal [3] but in general the lifetime of a component is limited by the weld [4]. In both cases there is a clear motive for the adoption of on-load monitoring techniques.

Weld failures are characterised by high localised strain and also cracking. A permanently installed, low-frequency, potential drop system is suggested as an appropriate tool which is sensitive to both indicators. Results from accelerated cross-weld creep tests will be presented showing excellent potential for monitoring power station components.

There are however difficulties taking potential drop readings in the vicinity of a weld as the differing electrical properties of the weld and parent material can interfere with the measurement, limiting the sensitivity. These issues will be explored.

Finally, a rate-based data interpretation framework will be presented as an appropriate means for remnant life calculation in a power station context.

References:

1. Guidelines for the Evaluation of Seam-Welded High-Energy Piping, Fourth Edition, EPRI1004329, 2003.
2. J. Parker, Component Matters, EPRI, October 2014.
3. Viswanathan and J. Stringer, J. Eng. Mater. Technol. 122 (3), 246-255, 2000.
4. I. J. Perrin and D. R. Hayhurst, International Journal of Pressure Vessels and Piping, 76, 9, 1999.

9:10 AM

Conformable Eddy Current Array Delivery

---Rahul Summan[1], Gareth Pierce[1], Charles Macleod[1], Gordon Dobie[1], Gary Bolton[2], Angélique Raude[3], Colombe Dalpé[3], and Johannes Braumann[4], [1]Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; [2]National Nuclear Laboratory, Chadwick House, Warrington Road, Birchwood Park, Warrington, WA3 6AE, United Kingdom; [3]Eddyfi Europe SAS, 110 Allée des Lilas, Les Fenières, Parc Industriel de la Plaine de l'Ain, 01150, Saint-Vulbas, France; [4]Association for Robots in Architecture, Vienna University of Technology, Karlsplatz 13, 1040 Wien, Austria

---The external surface of stainless steel canisters used for the interim storage of nuclear material is subject to Atmospherically Induced Stress Corrosion Cracking (AISCC). The inspection of such canisters poses a significant challenge due to the large quantities involved, therefore, automating the inspection process is of considerable interest. This paper reports upon a proof-of-concept project concerning the automated NDT of a set of test canisters containing artificially generated AISCC. An Eddy current array probe with a conformable padded surface from Eddyfi was used as the NDT sensor and end effector on a KUKA KR5 arc HW robot. A kinematically valid cylindrical raster scan path was designed using the KUKA|PRC path planning software. Custom software was then written to interface measurement acquisition from the Eddyfi hardware with the motion control of the robot. Preliminary results and analysis are presented from scanning two canisters.**---**This work was funded by the EPSRC Impact Acceleration Account.

9:30 AM

Experimental Validation of Ultrasonic NDE Simulation Software

---**G. Dib**, M. R. Larche, A. A. Diaz, S. L. Crawford, M. S. Prowant, and M. T. Anderson,
Pacific Northwest National Laboratory, Richland, WA 99354

---Computer modeling and simulation is becoming an essential tool for transducer design and insight into ultrasonic nondestructive evaluation (UT-NDE). As the popularity of simulation tools increases, it becomes important to assess their reliability to model acoustic responses from defects in operating components, and provide information that is consistent with in-field inspection data. This includes information about the detectability of different defect types for a given UT probe. Recently, a cooperative program between the Electrical Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC) was established to validate numerical modeling software commonly used for simulating UT-NDE of nuclear power plant components. In the first phase of this cooperative, extensive experimental UT measurements were conducted on machined notches with varying depth, length and orientation in stainless steel plates. Then, the notches were modeled in CIVA, a semi-analytical NDE simulation platform developed by the French Commissariat à l'Energie Atomique (CEA), and their responses compared with the experimental measurements. Discrepancies between experimental and simulation results are due to either improper inputs to the simulation model, or due to incorrect approximations and assumptions in the numerical models. To address the former, a variation study was conducted on the different parameters that are required as inputs for the model, specifically the specimen, flaw, and transducer properties. Then, the ability of simulations to give accurate predictions regarding the detectability of the different defects was demonstrated. This includes the results in terms of the variations in defect amplitude indications, and the ratios between tip diffracted and specular signal amplitudes.

9:50 AM

Development of Under-Sodium Viewing Technology for In-Service Inspection of Liquid Metal Fast Reactors

---**M. R. Larche**, D. L. Baldwin, M. K. Edwards, R. A. Mathews, T. S. Hartman, M. S. Prowant, and A.A. Diaz, Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352

---Optically opaque liquid sodium used in liquid metal fast reactors poses a unique set of challenges for nondestructive evaluation. The opaque nature of the sodium prevents visual examinations of components within this medium, but ultrasonic waves are able to propagate through sodium so an ultrasonic testing (UT) technique can be applied for imaging in sodium. A UT sensor used in liquid sodium during a refueling outage must be capable of withstanding the 260° C corrosive environment and must also be able to wet so that ultrasonic waves can propagate into the sodium. A multi-year iterative design effort, based on earlier work in the 1970s, has set out to improve the design and fabrication processes needed for a UT sensor technology capable of overcoming the temperature and wetting issues associated with this environment. Robust materials and improved fabrication processes have resulted in single element sensors and two different linear array sensors that have functioned in liquid sodium. More recent efforts have been focused on improving signal to noise ratio and image resolution in the highly attenuating liquid sodium. In order to accomplish this, modeling and simulation tools were used to design a 60 element 2D phased-array sensor operating at 2 MHz that features a separate transmitter and receiver. This design consists of 30 transmit elements and another 30 receive elements each arranged in a rectangular matrix pattern that is 10 rows tall and 3 wide. The fabrication of this 2D array is currently underway, and will be followed by a series of performance tests in water, hot oil, and finally in liquid sodium at 260°C. The performance testing cycle will evaluate multiple characteristics of the sensor that are crucial to performance including: transmit- uniformity, element sensitivity variations, element to element energy leakage, sound field dimensions, and spatial resolution. This paper will present a summary of results from the previous UT sensors as well as the results to date on the 2D phased-array sensor fabrication and evaluation.

10:30 AM

Analysis of High Temperature Ultrasonic Transducers for operation in liquid metal fast reactors-a Physics-based Modeling Approach

---Prathamesh N. Bilgunde, Leonard J. Bond (Center for NDE, Iowa State University)

Generation IV fast nuclear reactors are under development to support sustainable development, economic competiveness and improve safety. Past experience, specifically, with regard to long term maintenance experience from the Phoenix reactors (France) has underlined the need to provide effective and reliable inspection of components in any proposed advanced liquid metal cooled small modular, and other advanced reactors.

For last 40 years, many studies and reviews have been conveyed on the development of high temperature ultrasonic transducers. It has been identified that there is a necessity of a physics-based model to quantify the driving factors which limit the signal to noise ratio in liquid sodium at elevated temperature. This can help to reduce the cost of manufacturing and performance evaluation of the high temperature ultrasonic transducers.

The current study provides insights on the temperature effect on the amplitude of the ultrasonic signal. An ultrasonic NDE measurement system is basically a linear time-shift invariant system comprising of response functions. One such response function is the piezoelectric effect in which the piezoelectric element converts electric signal into a mechanical motion and vice versa to transmit and receive the ultrasonic signal respectively. The present study thus mainly concentrates on quantifying the effect of change in material properties of PZT-5A on the strength of the signal using finite element method. Effect of temperature variation on elastic constant, dielectric constant and piezoelectric constant and thus on the ultrasonic signal is analyzed one at a time. Finally, a complete material matrix is simultaneously simulated to report the reduction in the amplitude of the signal when the temperature of liquid sodium is increased from 105 to 195^{o}C. The finite element model simulates a pulse-echo set up for an ultrasonic transducer submerged completely into liquid sodium coolant. The simulation results and initial experimental room temperature data are analyzed together to begin to understand the limiting factors for performance of submerged ultrasonic transducer in liquid sodium at elevated temperature.

10:50 AM

Assessment of Key Indicators of Aging Cables in Nuclear Power Plants – Interim Status
---**S. W. Glass**, P. Ramuhalli, L. S. Fifield, M. S. Prowant, G. Dib, J. R. Tedeschi, J. D. Suter, A. M. Jones, M. S. Good, and A. F. Pardini, Pacific Northwest National Laboratory, Richland Washington

---Degradation of the cable jacket, electrical insulation, and other cable components of installed cables within nuclear power plants (NPPs) is known to occur as a function of age, temperature, radiation, and other environmental factors. With greater than 1000 km of power, control, instrumentation, and other cables typically found in an NPP, replacing all the cables would be a severe cost burden. The cable's ability to perform safely over the initial 40-year planned and licensed life has generally been demonstrated and there have been very few age-related cable insulation failures. Time-limited aging analyses, along with the use of appropriate aging management plans, have provided the necessary justification for life extension of plants (and the cable materials therein) to 60 years. With the focus now on a second license renewal, Justification for life extension to 80 years requires a cable insulation aging management program to justify cable performance under normal operation as well as accident conditions. Elongation at break (EAB) is currently the gold standard for determining cable insulation degradation. However, EAB is a destructive ex-situ measurement that requires laboratory investigation. Historically, maintenance personnel at operating NPPs have relied on a combination of subjective visual and tactile observations of cable insulation performed during plant walk downs to assess cable aging. A reliable nondestructive examination (NDE) approach is desirable to more objectively determine the suitability of the cable insulation material for continued service. As part of the Light Water Reactor Sustainability program sponsored by the U.S. Department of Energy, an assessment of possible cable insulation NDE methods is being studied. Technologies include tests of static and dynamic mechanical deformability (including indenter tests), infrared spectral measurements, electrical capacitance and acoustic measurements, plus tests of electrical impedance. This paper reports how these measurements are to be made as well as some early data collected on aged samples.

11:10 AM

Limitations of Eddy Current Testing in a Fast Reactor Environment

---**John Bowler**, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---The feasibility of using eddy current probes for detecting flaws in a fast reactor structures has been investigated. The primary requirement is to design probes and optimize their performance for the detection of flaws immersed in high temperature liquid metal in order to ensure the safe operation of the reactor. With these objectives in view, a parametric study has been carried out to evaluate the variation in probe performance as their parameters are changed, taking into account the effects of immersion in conductive coolant. In parallel with the work on eddy current probe optimization, we have designed a three axis scanning system to acquire eddy current data automatically in a liquid metal and used the data to validate simulations.---This work is funded by the Department of Energy under Award DE-NE0000676 and performed at Iowa State University

11:30 AM

Session 31

SESSION 31
PROFESSIONAL POSTERS
1:30 PM – 3:10 PM
Nicollet AB

NOTE: All Posters will be displayed continuously Monday through Thursday in Nicollet AB. During the Tuesday and Thursday afternoon poster sessions, the individual presenters will be on hand to answer questions.

Ultrasonics

Flaw Sizing Method Based on Ultrasonic Dynamic Thresholds and GRNN
---**Yongfeng Song**[1], Yiling Wang[1], Peijun Ni[3], and Xiongbing Li[1,2], [1]CAD/CAM Institute, Central South University, Changsha 410075, China; [2]State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, China; [3]The Ningbo Branch of Ordnance Science Institute of China, Ningbo 315103, China

Evaluation of Grain Size from Backscattering Signals Using the Finite Element Method
---Youxuan Zhao[1,2], Sivaramanivas Ramaswamy[3], **Shyamsunder Mandayam**[3], and Jianmin Qu[2]; [1]Southwest Jiaotong University, School of Civil Engineering, Chengdu 610031, China; [2]Northwestern University, Department of Civil and Environmental Engineering, Department of Mechanical Engineering, Evanston, IL 60208; [3]GE Global Research Centre, John F. Welch Technology Centre, Bangalore, 560066, India

Signal Phase Correction of Ultrasonic Synthetic Aperture Imaging for Inhomogeneous Materials with Uneven Surface
---**Lin Luo**, Caiqun Ye, and Xiaorong Gao, Southwest Jiaotong University, School of Physics Science and Technology, Chengdu, China 610031

Atomic Library Optimization for Sparse Pulse Ultrasonic Signal Decomposition and Reconstruction
---**Shoupeng Song**[1,2], Yingxue Li[1], and Aleksandar Dogandzic[2], [1]Jiangsu University, Department of Instrument Science and Engineering, Zhenjiang, China; [2]Iowa State University, Center for Nondestructive Evaluation, Ames, IA 50011

Advanced Defect Detection Algorithm Using Clustering in Ultrasonic NDE
---**Rui Gongzhang (presented by Jeffrey Dobson)** and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, G1 1XW

Ultrasound Scatter in Heterogeneous 3D Microstructures
---**R. Roberts** and R. Grandin, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50014

Techniques and Software Tools for Estimating Ultrasonic Signal-to-Noise Ratios
---**C.-P. Thomas Chiou**, Frank J. Margetan, Matthew McKillip, Brady J. Engle and Ron Roberts, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3042

Spatial Image Compounding Applied to a Phase Coherence Corrected UT-PA Technique for Inspecting Nuclear Components of Coarse-Grained Structure
---**Pablo Katchadjian** and Alejandro Garcia, Av. Gral Paz 1499, San Martin – Pcia, de Buenos Aires, Argentina

Non-Destructive Evaluation of Spiral-Welded Pipes Using Flexural Guided Waves
---Zhang Xiaowei[1], Tang Zhifeng**[2], and Lv Fuzai[1];** [1]Institute of Modern Manufacture Engineering, Zhejiang University, China 310027; [2]Institute of Advanced Digital Technologies and Instrumentation, Zhejiang University, China 310027)

Ultrasonic Instrumentation and Systems

Development of Ultrasonic Pulser for Large Displacement Wave Generation Using Soft PZT Element Transducer
---**Ren Koda**, Tsuyoshi Mihara, and Yoshio Udagawa, Tohoku University, Graduate School of Engineering, Sendai, Japan

Data Driven Force Control for Soft Dry Contact Hertzian Ultrasonic Probe
---**Emanuel Gallegos**, Arturo Baltazar, and Chidentree Treesatayapun, CINVESTAV, Robotics and Advanced Manufacturing Program – Saltillo Campus. Ramos Arizpe, Coahuila, 25903, México

Full-Matrix Capture and USB 3.0 for Open Platform Phased Array Instrument
---**Gavin Dao**[1], Remi Lallement[1], Ewen Carcreff[2] and Dominique Braconnier[2], [1]Advanced OEM Solutions, 8044 Montgomery Road #700, Cincinnati, OH, 45236; [2]The Phased Array Company, 9078 Union Centre Blvd., Suite 350, West Chester, OH, 45069

Development of an Ultrasonic Tomography System Based on Discrete Wavelets
---**Rodrigo Torres-Castillo** and Arturo Baltazar, Center for Research and Advanced Studies, Robotics and Advanced Manufacture Program, Saltillo Campus. Ramos Arizpe, Coahuila, 25903, Mexico

Detectability of Distributed Defects According to Synthetic Aperture Imaging Algorithm
---**Jongbeom Kim**[1], Hogeon Seo[1], Jihyun Jun[1], Kyung-Young Jhang[2], [1]Hanyang University, Department of Mechanical Convergence Engineering, Seoul 133-791, Republic of Korea; [2]Hanyang University, School of Mechanical Engineering, Seoul 133-791, Republic of Korea

Ultrasonic Concrete

Insights into Alkali Silica Reaction Damage in Concrete Through Acoustic Nonlinearity
---**Mohammad Mehdi Rashidi**, J.-Y. Kim, L. J. Jacobs, and K. E. Kurtis, Georgia Institute of Technology, 581 Morgan St. NE, Atlanta, GA 30308

Characterization of Stress-Induced Micro-Cracking in Concrete Using Nonlinear Acoustic Techniques
---**Parisa Shokouhi**[1], Colton R. Lake[2], Pierre-Yves Le Bas[2], Jacques Riviere[1], Robert Guyer[2], and T. J. Ulrich[2] [1]The Pennsylvania State University, University Park, PA 16802 [2]Los Alamos National Laboratory, Los Alamos, NM 87545

Multi-Mode Approaches

Multimode Model Based Defect Characterization in Composites
---**R. Roberts** and S. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50014

NDE Characterization in Developing Process Monitoring and Additive Manufacturing Quality Control
---**L. Koester**, J. Gray, and L. Bond, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50014

Non-Destructive Tools as an Aid in Fatigue Testing
---M. Mordasky, W. Zhao, and **G. C. Ojard**, United Technologies Research Center, East Hartford, CT 06108

Fusion of Multi-sensory Non-destructive Testing Data for Reliable Detection of Surface Cracks: Signal Level vs. Decision Level
---Rene Heideklang[1] and **Parisa Shokouhi**[2], [1]BAM Federal Inst. For Matls. Res. & Test, Unter den Eichen 87, Berlin 12205, Germany; [2]The Pennsylvania State University, University Park, PA 16802

AE Mechanisms of Stress Corrosion Cracking Under Micro Cell in SUS304 Stainless Steel
---**Mitsuharu Shiwa**, Hiroyuki Masuda, and Hisashi Yamawaki, National Institute for Materials Science, Materials Reliability Unit, Tsukuba; Kaita Ito and Manabu Enoki, The University of Tokyo, Department of Materials Engineering, Tokyo 113-8656, Japan

Ultrasonic and Magnetic Barkhausen Emission Measurements for Characterization of Pipeline Steels
---**Brady J. Engle**[1,2], Lucinda J. Smart[1,3,4], and Leonard J. Bond[1,2,3], [1]Center for Nondestructive Evaluation, 1915 Scholl Road, 111 ASC II, Iowa State University, Ames, IA 50011; [2]Department of Aerospace Engineering, 1200 Howe Hall, Iowa State University, Ames, IA 50011; [3]Department of Mechanical Engineering, 2025 Black Engineering, Ames, IA 50011; [4]Kiefner and Associates, 1608 S. Duff Avenue, Suite 400, Ames, IA 50010

Electromagnetic and Eddy Currents

Numerical Study on Distribution Law of Magnetic Field and Temperature Field Around the Crack Induced by Eddy Currents
---**Min He**, Wenpei Zheng, Laibin Zhang, and Fan Zhou, China University of Petroleum, College of Mechanical and Transportation Engineering, Beijing 102249, China

Numerical Calculation of the Yoke-Induced Electromagnetic Field in Ferromagnetic Planar Specimens for Use in Material Evaluation Applications: A Performance Study
---Thomas Svatoň and **Anastasios Skarlatos (presented by Roberto Miorelli)**, CEA LIST, Centre de Saclay, 91191, Gif-sur-Yvette cedex, France

Eddy-Current NDE Inverse Problem with Sparse Grid Algorithm
---**Liming Zhou**, Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, Bloomington, IN 47407-7706; William Bernacchi, Minds-Edge LLC, Indianapolis, IN 46268; John C. Aldrin, Computational Tools, Gurnee, IL 60031; David Forsyth, Texas Research Institute Austin, Austin, TX 78733-6201; Eric Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB, OH 45433-7817

Synthetic Transmit Aperture Imaging in Coarse Grained Steels
---Eduardo Lopez Villaverde[1], **Sébastien Robert**[1], and Claire Prada[2], [1]CEA LIST, 91191 Gif-sur-Yvette, France; [2]Institut Langevin, 1 rue Jussieu, 75238 Paris Cedex, France

Preliminary Research on Eddy Current Bobbin Quantitative Test for Heat Exchange Tube in Nuclear Power Plant
---**Pan Qi**, Shusheng Liao, and Hailin Wu, Center of In-service Inspection, China Nuclear Power Operation Technology Corporation, LTD, Wuhan, China 430223

Non Destructive Testing of High-Temperature Pipes Based on Low Frequency Eddy Current Imaging Using a Bobbin-Type Probe
---Jonghyun Seo, Soonbo Shim, Jungmin Kim, **Jinyi Lee**, and Hwa-shik Do, Chosun University, Department of Control and Instrumentation Engineering, Korea, KEPCO Plant Service & Engineering Co., Ltd., Korea

Database Generation and Exploitation for Efficient and Intensive Simulation Studies
---**R. Miorelli**, X. Artusi, and C. Reboud, CEA LIST, Departement Imagerie et Simulation pour le Controle, Gif-sur-Yvette, 91191, France

Further Capacitive Imaging Experiments Using Modified Probes
---**Xiaokang Yin**, An Yan, Zhen Li, Wei Li, and Guoming Chen, China University of Petroleum (East China), Centre for Offshore Equipment and Safety Technology, Qingdao 266580, China; David A. Hutchins, Warwick University, School of Engineering, Coventry CV4 7AL, United Kingdom

Application of Metal Magnetic Memory Technology on Jack-Up Platform
---**Changhang Xu**, Liping Cheng, Gang Wang, Guoming Chen, and Jing Xie, China University of Petroleum, Center for Offshore Engineering and Safety Technology, Qingdao, 266580, China

Surface Crack Detection for Polycrystalline Diamond Compact Bit Using Pulsed Eddy Current Thermography
---Naiwang Zhou, **Changhang Xu**, Jing Xie, and Xumei Gong, College of Mechanical and Electrical Engineering, China University of Petroleum, Qingdao, China

Microwave and MM Wave

Microwave and Millimeter Wave High-Resolution Imaging of Fiberglass Composites
---Mohammad T. Ghasr, Matthew J. Horst, and **R. Zoughi**, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Missouri University of Science and Technology (S&T), Rolla, MO 65409; Mario Lechuga, R. Rapoza, and C. Renoud, Fiberglass Structural Engineering (FSE), Inc., Bellingham, WA 98226

Vision/Optical/Thermal

Effect of Vibrational Behavior on Frictional Heating Mechanism in Vibrothermography
---**Wonjae Choi**[1*], Manyong Choi[1], Jeounghak Park[1], and Kooahn Kwon[2], [1]KRISS, Center for Safety Measurement, 267 Gajeong-Ro, Yuseong-Gu, Daejeon 305-340, Republic of Korea; [2]University of Science & Technology, Department of Aerospace System, 217 Gajeong-Ro, Yuseong-Gu, Daejeon 305-350, Republic of Korea

Structural Health Monitoring

WITHDRAWN - A 2-D Areal Scan for Imaging Composite Damage Using an Enhanced CCRTM Technique
---**Jiaze He**[1,2] and Fuh-Gwo Yuan[1,2], [1]National Institute of Aerospace, Center for Interated Structural Health Management, Hampton, VA 23666; [2]North Carolina State University, Department of Mechanical and Aerospace Engineering, Raleigh, NC 27695

X-Ray

MOVED TO SESSION 32 - Applications of an X-Ray NDE Simulation (XRSIM) for Developing and Optimizing Inspection Protocal for Aerospace Components—A Case Study
---**S. Singh**[1] and J. Gray[2], [1]Honeywell International, Inc., 110 S. 34th Street, M/S 503-118, Phoenix, AZ 85034; [2]Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Ultrasonics

Flaw Sizing Method Based on Ultrasonic Dynamic Thresholds and GRNN

---**Yongfeng Song**[1], Yiling Wang[1], Peijun Ni[3], Xiongbing Li[1,2], [1]CAD/CAM Institute, Central South University, Changsha 410075, China; [2]State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, China; [3]The Ningbo Branch of Ordnance Science Institute of China, Ningbo 315103, China

---A dynamic threshold method for ultrasonic C-Scan imaging is developed to improve the performance of flaw sizing: the reference test blocks with flat-bottom hole flaws of different depths and sizes are used for ultrasonic C-Scan imaging, a combination of Ostu's method, edge-preserving smoothing and mathematical morphology methods are proposed to preprocess the images. Thereafter, flaw regions are separated from the C-scan image through connected domain technique, and the point of maximum amplitude in flaw regions is obtained to get the amplitude and echo depth of flaw waves. Then the flaws are sized roughly by 6-dB-drop method. Based on the size of flat-bottom holes, enumeration method is used to get the optimal threshold for the flaw. The generalized regression neural network(GRNN) is trained using the combination of amplitude and echo depth of flaw waves, the rough size of flaw and the optimal threshold. Finally, the C-Scan image can be reconstructed according to dynamic threshold generated by trained GRNN. Compared with fixed threshold method, the experimental results show that the presented method has better performance and it is ideally suited for automatic analysis of ultrasonic C-scan images.---This work was supported by the National Natural Science Foundation of China (Grant nos. 61271356 and 51205031), Natural Science Foundation Hunan Province (Grant no. 14JJ2002), and China Postdoctoral Science Foundation funded project (Grant no. 2014M562126).

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Ultrasonics

Evaluation of Grain Size from Backscattering Signals Using the Finite Element Method

---Youxuan Zhao[1,2], Sivaramanivas Ramaswamy[3], **Shyamsunder Mandayam**[3], and Jianmin Qu[2]; [1]Southwest Jiaotong University, School of Civil Engineering, Chengdu 610031, China; [2]Northwestern University, Department of Civil and Environmental Engineering, Department of Mechanical Engineering, Evanston, IL 60208; [3]GE Global Research Centre, John F. Welch Technology Centre, Bangalore, 560066, India

---A numerical method for quantitative evaluation of grain size using ultrasonic signals was developed. In this method, an open source meshing software Neper was first used to generate a two-dimensional hardcore Voronoi tessellation for a polycrystalline solid with desired grain size. Crystallographic orientations are then assigned randomly to each grain. In the next step, a finite element mesh is constructed to conduct numerical simulations of wave propagation in the polycrystalline solid. In the finite element simulation, the material is assumed linearly elastic. Finally, two approaches, back-wall echo attenuation method in frequency domain and backscattered root mean square (RMS) grain noise method in time domain, were employed to estimate the average grain size. The grain size so obtained compares well with the actually grain size of the simulation cell.

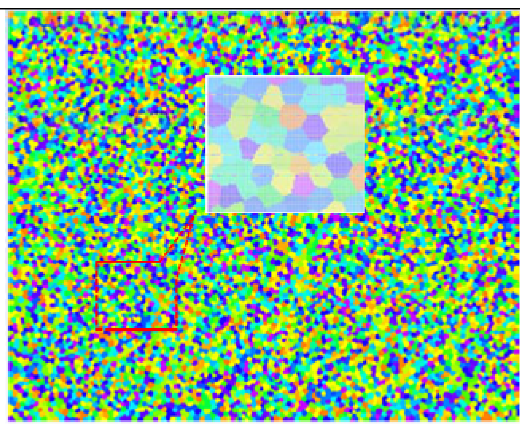

Fig. 1 A typical finite element mesh of a polycrystalline solid.

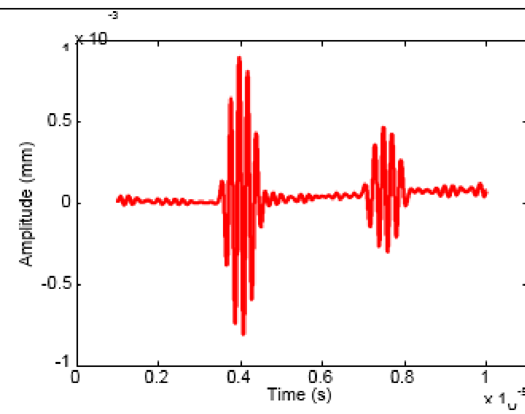

Fig. 2 A time signal from the back-wall echo attenuation method

Ultrasonics

Signal Phase Correction of Ultrasonic Synthetic Aperture Imaging for Inhomogeneous Materials with Uneven Surface

---**Lin Luo**, Caiqun Ye, and Xiaorong Gao, Southwest Jiaotong University, School of Physics Science and Technology, Chengdu, China 610031

---Amid the adoption of the technique of ultrasonic synthetic aperture imaging, when ultrasonic frequencies of receiving units are same and signals that received are synthesized and produce coherence superposition, the image data of each point are generated. With the increasing number of receiving units, the signal-to-noise ratio and the resolution ratio of images grows. Unfortunately, heterogeneity of dielectric materials and ups and downs of surfaces will cause phase error when signals of different receiving units are synthesized.

According to the sound wave emitted by the same defect point to each receiver unit with a similar waveform character, when signal of each unit have no phase-difference, the correlation between signals is maximum. Taking one of the unit signals as the reference signal, to calculate the correlation coefficient between other unit signal and the reference signal, in order to find the maximum movement value of the correlation coefficient, which is the phase difference that needs to be corrected. By using above methods, we correct the phase of all the received signals. Experimental result shows that after phase correction, the resolution of synthetic aperture ultrasound imaging has been improved effectively. In order to reduce the burden and the time to calculate, first we find the relevant defective areas before the correction, and just correct the phase of the points in defect areas. Adopt two window functions with mutual indemnification to do apodization with the imaging data, reducing the clutter in the image and the side lobe after correction. Experimental results show that after phase correction and data apodization, the image resolution of ultrasonic synthetic aperture has been significantly improved and the signal-to-noise ratio has increased 17dB.

Ultrasonics

Atomic Library Optimization for Sparse Pulse Ultrasonic Signal Decomposition and Reconstruction

---**Shoupeng Song**[1,2], Yingxue Li[1], and Aleksandar Dogandzic[2], [1]Jiangsu University, Department of Instrument Science and Engineering, Zhenjiang, China; [2]Iowa State University, Center for Nondestructive Evaluation, Ames, IA 50011

---Compressive sampling of pulse-echo ultrasonic NDE signals could bring significant savings in the data acquisition process. Sparse representation of these signals using an atomic library is key to their interpretation and reconstruction from compressive samples. However, the obstacles to practical applicability of such representations are: large size of the atomic library and computational complexity of the sparse decomposition and reconstruction. To help solve these problems, we develop a method for optimizing the ranges of scale-factor, time-shift, frequency, and phase parameters of modulated Gabor-atom library to match a real pulse-echo ultrasonic signal in terms of correlation. As a result of atomic-library optimization, the number of the atoms is greatly reduced compared with the traditional atomic library formation in [1]. To verify the feasibility of the proposed method, we employ numerical simulation technique to compare with the traditional method. Simulation results show that both the time efficiency and signal reconstruction energy error are superior to the traditional one even with small-scale atomic library (Fig.1). The performance of the proposed method is also explored under different noise levels (Fig.2). Finally, we apply the proposed method to real pipeline ultrasonic testing data, and the results indicate that our reduced atomic library outperforms the traditional library.---The authors thank NSFC (No. 51375217) for supporting this work.

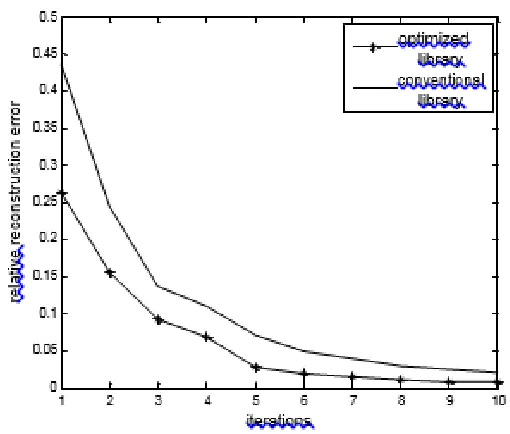

Fig. 1. Relative reconstruction error vs. Matching-pursuit iteration of conventional and optimized Gabor atomic libraries.

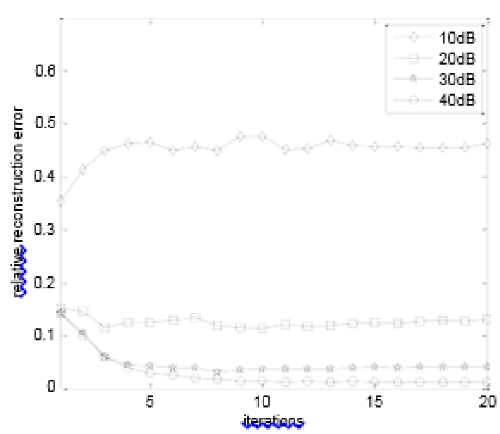

Fig. 2. Relative reconstruction error vs. matching-pursuit iteration for Different SNRs.

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Ultrasonics

Advanced Defect Detection Algorithm Using Clustering in Ultrasonic NDE

---**Rui Gongzhang** and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, G1 1XW

---A range of materials used in industry exhibit scattering properties which limits ultrasonic NDE. Many algorithms have been proposed to enhance the defect detect ability, such as the well-known Split Spectrum Processing (SSP) technique. But scattering noise usually cannot be fully removed and the remaining noise can be easily confused with real defect signals, hence becoming artefacts during the image interpretation stage. This paper presents an advanced algorithm to further reduce the effect of artefacts in A-scan data after initial processing using a conventional defect detection algorithm. The raw A-scan data can be acquired from either traditional single transducer or phased array. The proposed algorithm uses the concept of unsupervised machine learning to cluster segmental defect signals from pre-processed A-scans into different classes. The distinction and similarity between each class and the ensemble of randomly selected noise segments can be observed by applying a classification algorithm. Each class will then be labelled as 'real defects' or 'artefacts' based on this observation and the expected probability of defection & false alarm (PoD/PFA) determined. To facilitate data collection and validate the proposed algorithm, Full Matrix Capture (FMC) is applied on both austenitic steel and Inconel samples using a 5MHz linear array transducer. Each pulse-echo A-scan from the FMC dataset is pre-processed using SSP and the subsequent application of the proposed clustering algorithm has provided an additional reduction to PFA by around 20% while maintaining PoD for both samples compared with SSP results alone.---The authors wish to thank E.ON for the supply of samples and studentship support for Mr Gongzhang.

Ultrasound Scatter in Heterogeneous 3D Microstructures

---**R. Roberts** and R. Grandin, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50014

---This paper reports on a computational study of ultrasound propagation in heterogeneous metal microstructures. Random spatial fluctuations in elastic properties over a range of length scales relative to ultrasound wavelength can give rise to scatter-induced attenuation, backscatter noise, and phase front aberration. It is of interest to quantify the dependence of these phenomena on the microstructure parameters, for the purpose of quantifying deleterious consequences on flaw detectability, and for the purpose of material characterization. Previous work implemented a 2D computation of microstructure scattering using a volume integral equation (VIE) formulation. An iterative VIE solution evaluates the convolutional form of the VIE using fast Fourier transformation (FFT), yielding a computationally efficient algorithm. The present work is extending the implementation to 3D microstructures, using a GPU-based computational platform to carry out the volumetric convolutions. Realizations of random microstructures are specified on the micron scale using statistical property descriptions (e.g. grain size and orientation distributions), which are then spatially filtered to provide rigorously equivalent scattering media on a length scale relevant to ultrasound propagation. Scattering responses from ensembles of media representations are averaged to obtain mean and variance of quantities such as attenuation and backscatter noise levels, as a function of microstructure descriptors. The computational approach and GPU implementation will be summarized, and examples of application will be presented.---This material is based on work supported by the Iowa State University Center for Nondestructive Evaluation NSF Industry-University Cooperative Research Center.

Techniques and Software Tools for Estimating Ultrasonic Signal-to-Noise Ratios

---**C.-P. Thomas Chiou**, Frank J. Margetan, Matthew McKillip, Brady J. Engle and Ron Roberts, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3042

---The use of models to simulate ultrasonic inspections has played a key role in NDE R&D efforts for over 30 years. At Iowa State University's Center for Nondestructive Evaluation (CNDE), such work began in earnest with the development of the Thompson-Gray measurement model which allowed the pulse/echo A-scan response from small reflector in a test specimen to be predicted from knowledge of: (1) the far-field scattering amplitude of the reflector; and (2) pertinent information about the inspection system being used, including the radiation pattern of the transducer and the measurement system efficiency function for the conversion of electrical energy into sound. Over the years, a series of wave propagation models, flaw response models, and microstructural backscatter models have been developed at CNDE to address inspection problems of interest. One use of the combined models is the estimation of signal-to-noise ratios (S/N) in circumstances where backscattered echoes from the microstructure (grain noise) act to mask sonic echoes from internal defects. Such S/N models have been used to address questions of inspection reliability, such as how to optimize the choices of transducer properties and inspection design to insure that critical defects are reliably detected. Under the sponsorship of the National Science Foundation's Industry/University Cooperative Research Center at ISU, an effort was recently initiated to repackage existing research-grade software into user friendly tools for the rapid estimation of S/N for ultrasonic inspections of metals. The software combines: (1) a Python-based graphical user interface (GUI) for specifying an inspection scenario and displaying results; and (2) a Fortran-based engine for computing defect signal and backscattered grain noise characteristics. The later makes use of several models including: the Multi-Gaussian Beam Model for computing sonic fields radiated by commercial transducers; the Thompson-Gray Model for the response from an internal defect; and the Independent Scatterer Model for backscattered grain noise. The Stanke-Kino model is used for the computation of attenuation, and methods pioneered by James H. Rose are used for computing microstructural backscatter coefficients. This presentation provides an overview of the modeling effort and a demonstration of the first generation software. The initial emphasis was on reformulating the Fortran research-grade code into a suitable modular form, adding the graphical user interface and performing computations rapidly and robustly. Thus the initial inspection problem being addressed is relatively simple. A normal-incidence pulse/echo immersion inspection is simulated for a curved metal component having a non-uniform microstructure, specifically an equiaxed, untextured microstructure in which the average grain size varies with depth. The defect may be either a flat-bottomed-hole reference reflector or a spherical inclusion. In future generations of the software, microstructures and defect types will be generalized and oblique incidence inspections will be treated as well. Simulation outputs include estimated S/N as a function of the depth of the defect within the metal component, and, for any particular depth, a simulated A-scan displaying the superimposed defect signal and grain noise. A novel method is used for generating realistic grain noise waveforms. It makes use of representative measured grain noise signals which are stored and later altered to mirror the average strength and spectral characteristics of the backscattered noise as predicted for the simulation at hand.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Ultrasonics

Spatial Image Compounding Applied to a Phase Coherence Corrected UT-PA Technique for Inspecting Nuclear Components of Coarse-Grained Structure

---**Pablo Katchadjian** and Alejandro Garcia, Av. Gral Paz 1499, San Martin – Pcia, de Buenos Aires, Argentina

---The aim of this work is to obtain a C-Scan view of an austenitic stainless steel weld from a nuclear use pipe. In order to obtain this result Sectorial Scans (S-Scan) from both sides of the weld are obtained by Ultrasonic Phase Array (UT-PA). Then, spatial image compounding is performed to generate a single image from the S-Scans acquired at the same circumferential position of the transducer. These joints have a coarse grain structure which significantly reduce the transmission of the ultrasonic wave due to attenuation characteristics and backscattered noise from microstructures inside the material. For this reason, phase coherence imaging technique has been also applied to reduce the structural noise and improve the image quality. To verify detected defects, and given the impossibility of cutting the component, gammagraphy were performed with Co60.

Ultrasonics

Non-Destructive Evaluation of Spiral-Welded Pipes Using Flexural Guided Waves

---Zhang Xiaowei[1], **Tang Zhifeng**[2], and Lv Fuzai[1], [1]Institute of Modern Manufacture Engineering, Zhejiang University, China 310027; [2]Institute of Advanced Digital Technologies and Instrumentation, Zhejiang University, China 310027)

---Millions of miles of pipes are being used in both civil and industrial fields. Spiral-welded pipes, which are widely applied in fields such as drainage, architecture as well as oil and gas storage and transportation, are difficult to inspect due to their complex geometry. Guided waves have shown a great potential in Non-Destructive Evaluation (NDE) and Structural Health Monitoring (SHM) for such cases. Flexural guided waves which propagate at an angle relative to the axial direction of pipe, are the most appropriate modes for inspection of spiral-welded pipes. A time delay circular array transducer is proposed for the purpose of exciting pure flexural mode in pipes. The classical Normal Mode Expansion (NME) method [1] is adopted to disseminate the forced response and perturbation analysis of a steel pipe with respect to a time delay circular loading. Pure flexural mode can be excited when the time delay parameter is specially designed. The theoretical prediction is verified by finite element numerical evaluation and spiral-welded pipe inspection experiment.---The authors acknowledge the supports from the National Natural Science Foundation of China under Grant nos. 61271084 and 51275454.

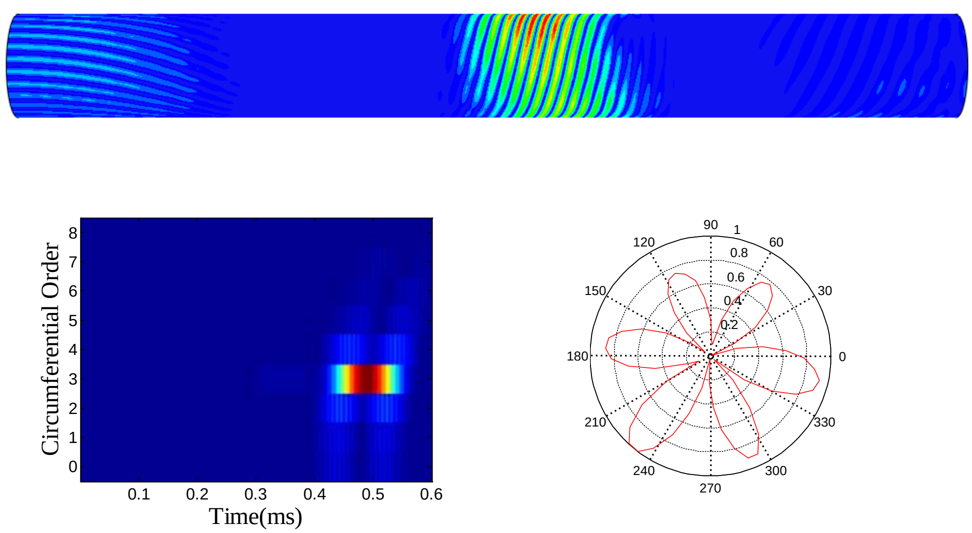

Figure 1. Numerical evaluation result for exciting pure T(3,1) mode in a steel pipe.

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Ultrasonic Instrumentation

Development of Ultrasonic Pulser for Large Displacement Wave Generation Using Soft PZT Element Transducer

---**Ren Koda**, Tsuyoshi Mihara and Yoshio Udagawa, Tohoku University, Graduate School of Engineering, Sendai, Japan

---For the industrial applications of ultrasound inspection, large amplitude of ultrasound transmission technique is required for several objectives such as to improve S/N ratio in the inspection of large attenuation materials [1], and generate nonlinear ultrasound at a crack [2]. However, conventional pulsers have limitations in generating larger signal amplitudes for two reasons: an impedance mismatch between transducer and pulser, and an unsustainable electric current at the higher voltage excitations. To overcome these limitations, we developed a new pulser using a SiC transistor to have a large current available. In this study, we focused on the relationship of impedance and designed the low output impedance of the pulser with 0.5 Ω. We prepared several transducers having different impedances depending on the size, and the material of PZT hard and soft. Then, we measured signal amplitude, effective voltage, and electric current when the transducers were excited with a 5-cycle tone burst of 4-MHz longitudinal wave (Fig.1). Among the low impedance transducers, a large difference of voltage drop was observed under the conventional pulser excitation due to voltage dividing, whereas the difference decreased when driven with the SiC transistor pulser. In particular, when the soft PZT transducer is excited with the highest voltage setting of the SiC transistor pulser, the displacement is about 300 nm, which is about two times larger than that of hard PZT. In the future, we will improve our pulser using a new transistor that responds to higher frequencies and consider noise reductions of excitation waveforms.---This work was partially supported by a Grant-in-Aid for the Innovative Nuclear Research and Development Program (No.120804) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

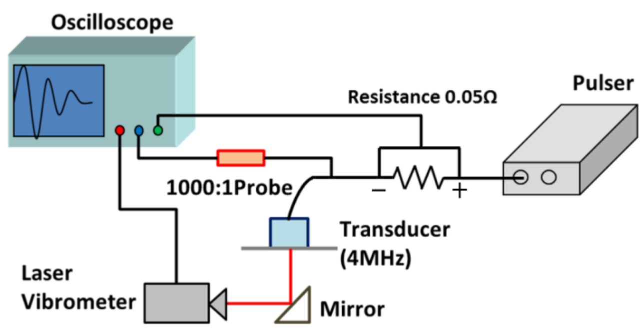

Figure 1. Schematic of the experimental setup for measurements of amplitude, voltage, and current of ultrasound signals.

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Data Driven Force Control for Soft Dry Contact Hertzian Ultrasonic Probe

---**Emanuel Gallegos**, Arturo Baltazar, and Chidentree Treesatayapun, CINVESTAV, Robotics and Advanced Manufacturing Program – Saltillo Campus. Ramos Arizpe, Coahuila, 25903, México

---In the automotive industry, the fast-paced manufacturing processes and the need for a sound relationship between cost and time per inspected part require the automation of currently used ultrasonic manual tests which are required to locate and characterize hidden flaws (Figure 1). In many cases, contact testing is performed with limited information on the surface properties, as well as location, shape, and orientation of the hidden flaws. In this work a control algorithm based on data driven control with multi-inputs is proposed to control the contact area generated between the probe and the test object. The proposed control requires no previous knowledge of the system or information of the physical model, instead it uses the information provided by measurements of the system in order to adjust the control parameters. As shown in [1] the control algorithm can incorporate information provided by ultrasound (time of arrival, frequency, amplitude of the reflected wave and phase) as well as data from visual cameras to control position and area of contact of a soft ultrasonic probe to locate hidden damage in a test object. The experimental system is described in Figure 2. The proposed deformable soft probe is used in conjunction with a 3 DOF Cartesian robotic manipulator (Figure 2A) for automated NDE testing [2]. The experimental results demonstrate the performance of our proposed controller with the convergence of regulation and tracking tasks regarding to ultrasonic signals obtained by the contact probe. Additional experiments for the estimation of the real contact area and vertical deformation using a camera and ultrasound shows a hysteretic and nonlinear behavior of the proposed soft probe.

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1. J. Armendariz, C. Treesatayapu and A. Baltazar, "Development of an estimated force feedback controller based on Hertzian contact and ultrasound," Robotic and Sensors Environments (ROSE), 2010 IEEE International Workshop on, Phoenix, AZ, pp 1-6 (2010).
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<u>**Ultrasonic Instrumentation**</u>

Full-Matrix Capture and USB 3.0 for Open Platform Phased Array Instrument
---**Gavin Dao**[1], Remi Lallement[1], Ewen Carcreff[2] and Dominique Braconnier[2], [1]Advanced OEM Solutions, 8044 Montgomery Road #700, Cincinnati, OH, 45236; [2]The Phased Array Company, 9078 Union Centre Blvd., Suite 350, West Chester, OH, 45069

---Nondestructive evaluation (NDE) using ultrasonic waves is an efficient technique to assess industrial component integrity. The use of array probes enables inspection flexibility and advanced imaging techniques such as the total focusing method (TFM). In particular, the TFM imaging approach tremendously increases the quantity of data compared to conventional ultrasonic testing. Data transfer rates from the ultrasonic equipment to the computer are therefore continuously increasing due to large quantities of data and high speed inspections. In this work, we propose to use a USB 3.0 communication protocol for high speed throughput in a phased array device. To our knowledge, such protocol has not be proposed before for such an equipment. In this paper, we show that this protocol offers high transfer rates and is suitably adapted to ultrasonic inspection with array probes.

Ultrasonic Instrumentation

Development of an Ultrasonic Tomography System Based on Discrete Wavelets

---**Rodrigo Torres-Castillo** and Arturo Baltazar, Center for Research and Advanced Studies, Robotics and Advanced Manufacture Program, Saltillo Campus. Ramos Arizpe, Coahuila, 25903, Mexico

---The characterization of discontinuities such as porosities or inclusions in metallic parts made from metal casting process in automotive manufacturing is needed. Tomography using x-rays can be used to characterize their internal complexities without the need to invade them. However, the exposure to radiation represents a potential health risk. As an alternative, tomography using parameters of ultrasonic signals has been proposed [1]. The optimization of the number of projections using a limited number of transducers as well as the use of an array of transducers was studied [2]. Sound diffraction correction using algorithms in time and frequency domain has been addressed in the literature [3]. Here, we propose tomography reconstruction accomplished with a Cartesian robot and a limited number of ultrasonic transducers to generate the needed projections of the metallic cylinder object. The signals are transformed using a proposed discrete wavelet algorithm [4] for the identification of arrival time and energy content in the signal. The diffraction is accounted for by first simulating the tomography of the object without defects using finite differences [5]. Experiments were performed on cylindrical samples of Cobalt casting with dimensions of 15mm in diameter and 70mm in length. A set of two commercial ultrasonic transducers in a thru-transmission configuration are fixed and in between them, the cylindrical test part is placed and rotated by the Cartesian robot to obtain the projections needed (Figure 1). As preliminary results, a 3D reconstruction was obtained using a filtered-back projection (Figure 2) and the proposed methodology. It was possible to characterize the internal discontinuities with sufficient resolution.

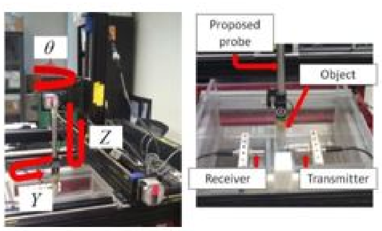

Figure 1. Experimental setup.

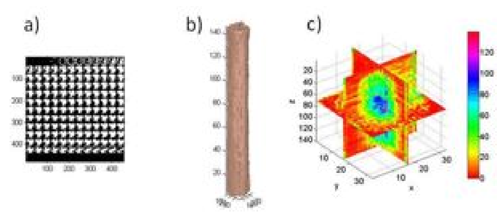

Figure 2. a) 2D reconstruction of each slice of the object; b) 3D reconstruction and; c) Internal view.

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Ultrasonic Instrumentation

Detectability of Distributed Defects According to Synthetic Aperture Imaging Algorithm

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---Ultrasonic imaging has been widely utilized as an intuitive tool for nondestructive evaluation (NDE) in medical as well as industrial fields [1]. Since high quality and accurate image of the diagnosed result can significantly contribute to realization of quantitative non-destructive evaluation, many imaging techniques such as B-scan, synthetic aperture focusing technique (SAFT), total focusing method (TFM) have been developed [2]. Although there are some researches to compare the resolution and effectiveness between synthetic aperture imaging algorithms: common-source method (CSM), SAFT, TFM, and sparse TFM, the detectability according to various kinds of distributed defects has not studied well [3]. To figure out whether a certain synthetic aperture algorithm has superiority regardless of the distribution type of flaws or each has pros and cons for specific cases, this study carried out the experiment with array probes for imaging the defects distributed vertically or horizontally. The sensitivity of each element in exciting and receiving ultrasounds were compensated as well as its directivity was also considered. The same data set acquired through full matrix capture (FMC) was post-processed by SAFT, TFM, sparse TFM to reconstruct result images, respectively. The axial and lateral resolutions according to reconstruction algorithm were compared of each other. The results showed that the combination of synthetic aperture imaging algorithms is necessary to effectively detect various cases of distributed flaws at a time. TFM was good at imaging defects spread vertically; whereas, SAFT had better performance to visualize the cases scattered horizontally. This implies that it is recommended and better for imaging the defects of which the distribution is unknown to utilize synthetic aperture imaging algorithms together than to use only one method. --- This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (NRF-2013M2A2A9043241). The corresponding author is Kyung-Young Jhang whose email address is kyjhang@hanyang.ac.kr.

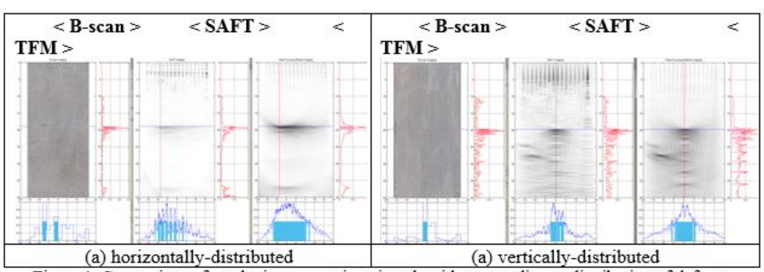

Figure 1. Comparison of synthetic aperture imaging algorithm according to distribution of defects.

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Ultrasonic Concrete

Insights into Alkali Silica Reaction Damage in Concrete Through Acoustic Nonlinearity
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---In concrete materials, the product of the alkali silica reaction (ASR) is a gel which in the presence of water expands and causes damage, including micro-cracking. Nonlinear acoustic techniques have been successfully used to nondestructively quantify the damage through assessment of changes in material properties related to micro-cracking. A petrographic method **–** the damage rating index (DRI) -can provide a measure of the degree of ASR damage present in concrete materials, often from cores obtained from existing structures, based upon crack patterns and the presence of ASR products. The current research examines the relationship between the DRI and acoustic nonlinearity to quantify damage state in ASR-affected mortar. The results show a very good correlation between these two parameters, and helps in understanding the sequence of ASR damage evolution.

Ultrasonic Concrete

Characterization of Stress-Induced Micro-Cracking in Concrete Using Nonlinear Acoustic Techniques

---**Parisa Shokouhi**[1], Colton R. Lake[2], Pierre-Yves Le Bas[2], Jacques Riviere[1], Robert Guyer[2], and T. J. Ulrich[2] [1]The Pennsylvania State University, University Park, PA 16802; [2]Los Alamos National Laboratory, Los Alamos, NM 87545

---We summarize the results of three nonlinear acoustic tests performed on a series of eight (8) stress-damaged concrete samples. All the samples are cut out of a single concrete block. We induce various levels of damage by compressing each sample to a certain percentage of the mix nominal strength (obtained by crushing a cube extracted from the same block). NRUS (non-linear resonant ultrasound spectroscopy) is performed on all the eight samples and repeated three times. The testing based on SSM (scaling subtraction method) is performed on a subset of the samples. We conduct DAET dynamic acousto-elasticity testing (DAET) only on the undamaged and most-damaged samples. Both NRUS and SSM can differentiate between intact and damaged samples and as expected, yield similar results. DAET clearly distinguishes between the intact undamaged and most-damaged specimen. We further demonstrate that neither linear velocities nor linear elastic moduli can delineate undamaged and damaged concrete.

Multi-Mode Approaches

Multimode Model Based Defect Characterization in Composites

---**R. Roberts**, S. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50014

---This paper reports on work newly underway to explore of model based defect characterization methods for NDE of CFRP composites. The work is examining defect responses obtained with ultrasound and thermography, for the purpose of classifying and characterizing the defect through combined analysis of the multiple-mode data. Analysis is premised on the availability of forward scattering models to predict NDE response to specified defects. The approach to defect characterization identifies a set of parameters describing the defect, then optimizes agreement between NDE measurements and measurement predictions through manipulation of defect descriptors, subject to ancillary measures of defect properties imposed to regularize an otherwise ill-posed inversion. Motivation for the project is the detection and characterization of defects in out-of-autoclave large composite structures. Defects of interest in these structures are excessive porosity, delamination, and fiber misalignment. Initial work is examining the effectiveness of ultrasound and thermography in discriminating between delamination and porosity. This presentation will summarize the forward measurement models being adapted for this purpose, and will outline the approach being taken to implement a well-conditioned inversion. Examples will be presented using synthetic scattering data, as well as any experimental data available by July 2015.---This material is supported by NASA through Early Stage Innovation grant #NNX15AD75G.

Multi-Mode Approaches

NDE Characterization in Developing Process Monitoring and Additive Manufacturing Quality Control

--**Lucas Koester**, Leonard J. Bond, J.N. Gray, F. Margetan and D. Barnard. Center for NDE, Iowa State University, Ames Iowa 50011

--Additive manufacturing (AM) is a process of joining material s to make objects from 3D model data, usually layer upon layer, as opposed to processes that employ subtractive methods. AM is seeing dramatic growth with a 26.2% annual growth rate as of 2012 and a predicted worldwide market valued at $5 billion by 2020. This technology is being used to create components with geometries that are difficult or impossible to create with subtractive machining methods.

AM has a need for innovative methods of process monitoring and control to improve part-to-part consistency and quality. Issues include the relatively expensive of powder materials, generally slow build rates (lbs/hr), and high initial machine costs make this best suited for low production runs or prototyping.

This poster will consider some of the needs and challenges encountered in AM. The end application of a component identifies the design and manufacturing allowables, i.e. what is and is not a defect. Defects in AM parts are similar to those seen in casting and welding processes. However, other factors outside of the particular method used contribute to defect formation, including the raw materials used (powder, wire, etc.), the processing para1neters, and any additional process part treatment performed at the end of the process, such as hot isostatic pressing or heat treatment.

Given the possibility of forming defects at any point during the process, an alternative approach to NDE must be taken that encompasses the entire process, from raw material to final part. Advanced NDE when developed can not only help identify defects but also aid in optimization of the process from raw material to final part, so as to minimize cost.

<u>Multi-Mode Approaches</u>

Non-Destructive Tools as an Aid in Fatigue Testing

---M. Mordasky, W. Zhao, and **G. C. Ojard**, United Technologies Research Center, East Hartford, CT 06108

---A series of fatigue tests were done on aluminum samples with a through hole. This standard testing was done with and without a composite patch on each side of the coupon. The testing was done to determine if the patch improved the fatigue life of the aluminum base material. Due to the presence of the through hole, crack initiation was monitored with an eddy current hole probe. The composite patch hindered the use of normal optical methods of tracking a crack during such tests. The ability to inspect the material was critical in understanding how the overall hybrid performed. A final set of testing was done to determine if delaminations were critical at the bond-line between the composite and the aluminum. This brought ultrasonic inspection into the NDE tool use. The results of this were difficult to analyze as the impedance mismatch and the defect generation proved to be a challenge. The results and fatigue data will be presented.

Multi-Mode Approaches

Fusion of Multi-Sensory Non-Destructive Testing Data for Reliable Detection of Surface Cracks: Signal Level vs. Decision Level

---Rene Heideklang[1] and **Parisa Shokouhi**[2], [1]BAM Federal Inst. For Matls. Res. & Test, Unter den Eichen 87, Berlin 12205, Germany; [2]The Pennsylvania State University, University Park, PA 16802

---We present and compare two different approaches for NDT multi-sensor data fusion at signal (low) and decision (high) levels. Signal-level fusion is achieved by applying simple algebraic rules to strategically post-processed images. This is done in the original domain or in the domain of a suitable signal transform. The importance of signal normalization for low-level fusion applications is emphasized in regard to heterogeneous NDT data sets. For fusion at decision level, we develop a procedure based on assembling joint kernel density estimation (KDE). The procedure involves calculating KDEs for individual sensor detections and aggregating them by applying certain combination rules. The underlying idea is that if the detections from more than one sensor fall spatially close to one another, they are likely to result from the presence of a defect. On the other hand, single-senor detections are more likely to be structural noise or false alarm indications. To this end, we design the KDE combination rules such that it prevents single-sensor domination and allows data-driven scaling to account for the influence of individual sensors. We apply both fusion rules to a three-sensor dataset consisting in ET, MFL/GMR and TT data collected on a specimen with built-in surface discontinuities. The performance of the fusion rules in defect detection is quantitatively evaluated and compared against those of the individual sensors. Both classes of data fusion rules result in a fused image of fewer false alarms and thus improved defect detection. Finally, we discuss the advantages and disadvantages of low-level and high-level NDT data fusion with reference to our experimental results.

Multi-Mode Approaches

AE Mechanisms of Stress Corrosion Cracking under Micro Cell in SUS304 Stainless Steel

---**Mitsuharu Shiwa**, Hiroyuki Masuda, and Hisashi Yamawaki, National Institute for Materials Science, Materials Reliability Unit, Tsukuba; Kaita Ito and Manabu Enoki, The University of Tokyo, Department of Materials Engineering, Tokyo 113-8656, Japan

---Acoustic emission (AE) and optical video microscope (VMS) monitoring was proposed to evaluate the stress corrosion cracking (SCC) mechanism of type 304 stainless steels in work-hardened (WH) and solution heat treatment (ST) specimen caused by a small magnesium-chloride droplet as shown in Fig.1. The crack propagation length could be measured clearly under the droplet with coved glass by VMS. The crack velocities of WH were 3.2-4.7 μm/ks and it propagated almost continuously. That of ST were 2.1-3.8 μm/ks and it propagated similar to WH. AE signals were generated at early stage of SCC testing, after that, they were generated discontinuously in WH as shown in Fig.2. No AE signals were detected in ST. The detected AE signals were synchronized with small bubbling on the crack in a droplet observed by high magnification VMS. With the cross-section SEM observations, covered pitting under the crack was observed at the bubbling position. In the cross-section images of crack tip by SEM, WH and ST crack tips were located under the specimen surface. As the SCC mechanism could not HC and APC, we have to consider the AE measurement setting for hydrogen-induced transformation detection.

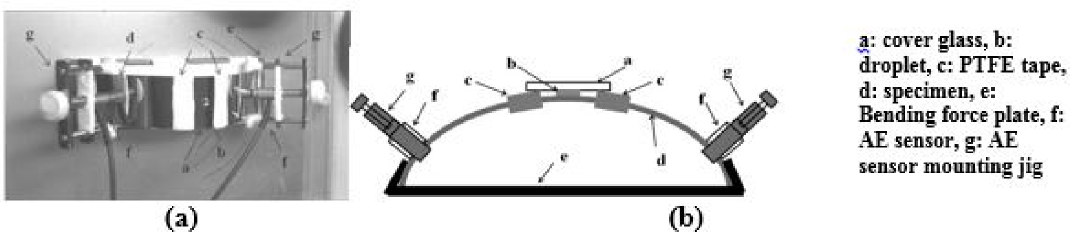

Figure 1. Specimen and measurement settings, photo (a) and schematic representing specimen loading and AE sensor mounting (b).

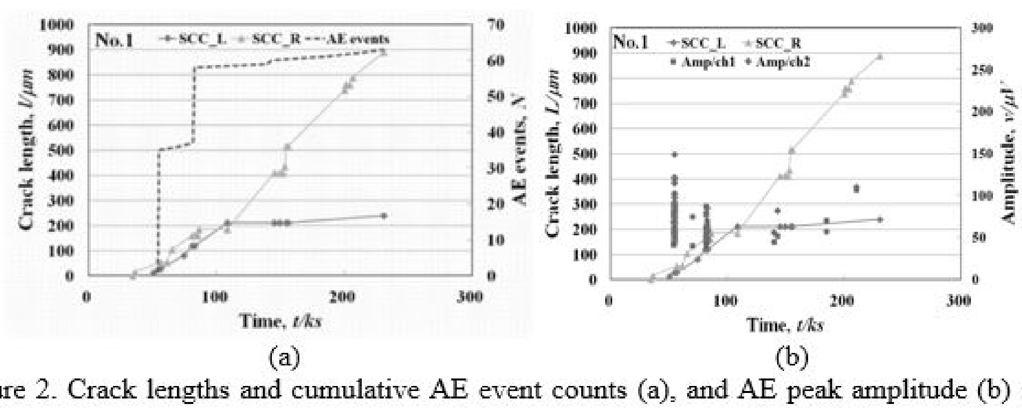

Figure 2. Crack lengths and cumulative AE event counts (a), and AE peak amplitude (b) in WH.

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Multi-Mode Approaches

Ultrasonic and magnetic Barkhausen emission measurements for characterization of pipeline steels

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To ensure that the aging pipeline infrastructure in the USA can be safely operated, the mechanical properties of the pipe materials must be verified. It is hypothesized that characterization of the pipeline steels and their microstructures through nondestructive methods will allow for the estimation of the mechanical properties of interest, namely yield strength, tensile strength, toughness, and ductile-to-brittle transition temperature. This work will discuss how material properties, such as microstructure and chemical composition, affect the mechanical properties as well as strategies for measuring the material properties nondestructively using magnetic Barkhausen emission and ultrasonic velocity and attenuation measurements. Preliminary results on a limited sample set will be shown and challenges encountered will be discussed.

Electromagnetic and Eddy Currents

Numerical Study on Distribution Law of Magnetic Field and Temperature Field Around the Crack Induced by Eddy Currents

---Min He, Wenpei Zheng, Laibin Zhang and Fan Zhou, China University of Petroleum, College of Mechanical and Transportation Engineering, Beijing 102249, China

---Eddy current thermography is a nondestructive testing technology emerging in recent years. In this method, eddy currents induced in the conductor under inspection can heat the conductor. If a crack exists, the temperature field disturbance around the crack will appear.
Alternative current field measurement (ACFM) and eddy current thermography are both induced by eddy currents, and it is a commonality between them. The commonality has laid a good foundation for the combination of the two testing techniques, which can give a more reliable result than a single technique. In this paper, a numerical study on distribution law of magnetic field and temperature field around the crack using eddy current excitation is carried out. The feasibility of the combination of ACFM and eddy current thermography is discussed as well. Two types of specimens respectively made of non-ferromagnetic and ferromagnetic materials are tested by the inducer, and each specimen has a semielliptical crack. The distribution law of magnetic field and temperature field is both studied using the same eddy current excitation. Compared with ACFM, eddy current thermography needs an excitation current with larger value and higher frequency. Based on this reason, the excitation current with large value and high frequency is adopted in this paper, and the comparison and selection of the different current values and frequencies are made to ensure fine detection features. By changing the number of coil turns and the lift-off height of the inducer, the optimal excitation parameters are determined. The magnetic field distortion, the optimal testing time and the maximum temperature difference around the crack are obtained. The relationship between the crack size and distribution of magnetic field and temperature field is identified by altering the length, width and depth of the crack. Through comparisons, the magnetic distribution law around the crack in this paper is consistent with that of ACFM, and the maximum temperature difference around the crack meets the inspection requirement of a thermal imager. These findings might make it possible to eventually combine ACFM and eddy current thermography.---The work is supported by the National Natural Science Foundation of China (No. 51404283).

Electromagnetic and Eddy Currents

Numerical Calculation of the Yoke-Induced Electromagnetic Field in Ferromagnetic Planar Specimens for Use in Material Evaluation Applications: A Performance Study

---Thomas Svatoň and Anastassios Skarlatos, CEA LIST, Centre de Saclay, 91191, Gif-sur-Yvette cedex, France ***(Poster will be presented by Roberto Miorelli of CEA)***

---The electromagnetic yoke is one of the standard methods of producing high-intensity magnetic fields in ferromagnetic specimens for material evaluation purposes as well as for flaw detection techniques like magnetic flux leakage and magnetic particle inspection [1]. To properly address this problem from the simulation point of view is a very challenging task, because of the non-linear, and, in most cases, hysteretic character of both the specimen and the yoke core material. Although modern numerical codes are now capable of tackling the non-linear, hysteretic problem, the obtained precision and performance of the solver are usually strongly dependent on the applied computational mesh, on tuning parameters of the iterative scheme used for the inversion of the non-linear operator and even on the hysteresis model that is used for the representation of the material B-H curve. Hence, the quality of the numerical solution heavily relies on the experience of the user, and must be always subjected to verification tests. In terms of the performance, an optimal choice of the aforementioned parameters may also reduce significantly the computational time. In this contribution, a number of different iterative approaches (Picard-Banach, Newton-Raphson as well as hybrid approaches) are combined with a 2D numerical solver based on the finite integration technique (FIT) for the solution of the non-linear, hysteretic problem, depicted in the figure below [2]. The main motivation for this work is twofold: on one side to evaluate the performance of the different approaches for the application in the concrete case of material evaluation procedures involving the yoke configuration, and, on a second level to establish a number of criteria and rule of thumbs in order to provide reliable results in a quasi-automated simulation procedure. In addition, the impact of different hysteresis models to the results will be studied.

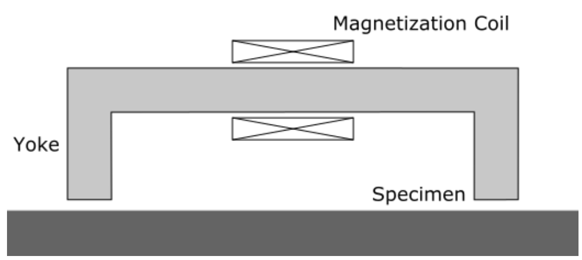

Figure: The yoke configuration.

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<u>**Electromagnetic and Eddy Currents**</u>

Eddy-Current NDE Inverse Problem with Sparse Grid Algorithm

---Liming Zhou, Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, Bloomington, IN 47407-7706; William Bernacchi, Minds-Edge LLC, Indianapolis, IN 46268; John C. Aldrin, Computational Tools, Gurnee, IL 60031; David Forsyth, Texas Research Institute Austin, Austin, TX 78733-6201; Eric Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB, OH 45433-7817

---In the model-based inverse problems, the unknown parameters (such as length, width, need to be estimated. When the unknown parameters are few, the conventional mathematical methods are suitable. But the increasing number of unknown parameters will make the computation become heavy. The equations need be solved increased exponentially with the number of parameters. To reduce the burden of computation, the sparse grid algorithm which is introduced by Sergey A. Smolyak was used in our work. It is a family of constructing multidimensional quadrature and interpolation rules from tensor products of one dimension. As a result, we obtain a powerful interpolation method that requires significantly fewer support nodes than conventional interpolation on a full grid. In this work, we combined sparse grid toolbox TASMANIAN which is produced by Oak Ridge National Laboratory and professional eddy-current NDE software **VIC-3D®** to solve a specific inverse problem. In this problem, a crack was simulated by four blocks which each of them having a different depth. We show that the sparse grid interpolated results agree well with model calculations made by **VIC-3D®**.---This work was supported by the Air Force Research Laboratory through SBIR Contract FA865-13-C-5011 with Victor Technologies, LLC.

Electromagnetic and Eddy Currents

Synthetic Transmit Aperture Imaging in Coarse Grained Steels

---Eduardo Lopez Villaverde[1], **Sébastien Robert**[1] and Claire Prada[2] [1]CEA LIST, 91191 Gif-sur-Yvette, France; [2]Institut Langevin, 1 rue Jussieu, 75238 Paris Cedex, France

---In ultrasonic imaging, the Total Focusing Method (TFM), also known as Synthetic Transmit Aperture (STA), is a time-domain algorithm that provides an optimal focusing and spatial resolution everywhere in a region of interest. This algorithm is particularly interesting in NDT to enhance the characterization of crack-type defects. In the present work, the STA technique is applied to coarse grained austenitic-ferritic steels of the nuclear industry using a contact phased array probe. The highly heterogeneous structure of these materials may produce a strong noise in ultrasonic imaging. Furthermore, interface guided waves interfere with the bulk waves. In order to overcome these problems, the method of Decomposition of the Time Reversal Operator (DORT) is applied before calculating the STA image. The DORT method consists of the analysis in the frequency domain, of the singular values and vectors of the inter-element impulse response matrix. The noise filtering is obtained by separating the signal sub-space from the noise sub-space for each frequency in the transducer band-width. The signal sub-space identification is based on cross-correlations of the singular vectors with a reference one (e.g., the singular vector at the central frequency or a theoretical one). Then, a filtered matrix is redefined and an inverse Fourier transform is applied to come back in the time domain. Finally, the STA algorithm is applied to the filtered matrix to form an image with a reduced structural noise. Experiments performed with a coarse grained steel specimen demonstrate that the DORT filtering improves the signal-to-noise ratio up to 14 dB compared to the STA image before filtering.

Preliminary Research on Eddy Current Bobbin Quantitative Test for Heat Exchange Tube in Nuclear Power Plant

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---Eddy current bobbin inspection is the mainly quantitative test method for heat exchange tube of steam generator (SG) in nuclear power plant (NPP). Due to various interactions with others, such as skin effect, pipe quality, instrument noise, consistency of defects type between calibration and actual tube, defects orientation and scale and so on, the actual accuracy of quantitative method is weak. The crack as a primary degraded form of SG heat exchange tube has been studied on quantitative techniques on this paper. (1)The production optimization of calibration tube. Based on the control of parts of the factors, the intuitive analysis is carried by comparison of defect depth quantitative absolute deviation under crack calibration tube, ASEM calibration tube and RSEM calibration tube to determine the crack tube as an ideal quantitative calibration tube. The multiple linear regression and ridge regression is applied to weight analysis of the orientation and scale of cracks affect the depth of defect quantitative which make calibration tube production optimized. (2)Depth quantitative accuracy optimization. According to the raw data acquisition under the crack calibration tube, BP neural network as a data fusion algorithm which is used to fuse original quantitative data based on multiple phase vs depth calibration curve establish the optimization model to optimize natural crack depth quantitative results. Based on the methods above, the crack depth quantitative accuracy can be improved in a certain extent.

Non Destructive Testing of High-Temperature Pipes Based on Low Frequency Eddy Current Imaging Using a Bobbin-Type Probe

---Jonghyun Seo, Soonbo Shim, Jungmin Kim, **Jinyi Lee**, and Hwa-shik Do, Chosun University, Department of Control and Instrumentation Engineering, Korea, KEPCO Plant Service & Engineering Co., Ltd., Korea

---In the past, global energy markets have undergone a shift from thermal, wind, and solar to nuclear power generation. However, since the accident in 2011 at the Fukushima nuclear power plant in Japan, there has been a renewed focus on thermal-power generation. The need to reduce carbon dioxide (CO_2) emissions continues to be one of the main problems however, and several studies are being performed to reduce CO_2 emissions while realizing high-efficiency power generation. One method, called ultra-supercritical (USC) method, involves the use of vaporized coal at high pressures exceeding 246 kg/cm^2 and high temperatures exceeding 593℃. Therefore, components that transfer the high-temperature and high-pressure medium are made with anti-temperature strong materials, such as 9Cr-1Mo steel. On the other hand, the reliability of high-temperature structures is affected by creep and creep-fatigue damages. Moreover, to maintain the reliability of USC-type thermal power generation, damages have to be inspected and quantitatively evaluated using advanced nondestructive testing techniques. However, damages to the small bore-pipe made with 9Cr-1Mo steel are not easy to inspect because 9Cr-1Mo steel is a high-permeability ferromagnetic material, and it is more difficult to inspect it for damage when using conventional eddy current testing (ECT) techniques. In this paper, we propose an advanced nondestructive testing method that uses a bobbin-coil and 22 circumferentially arrayed Hall sensors. The coil comprises a 0.1 mm thick winding with 80 turns. We inputted a 700 Hz, 300 mA AC current to the coil, and inserted the coil and arrayed sensors into the specimen, which has an inner diameter of 12.7 mm and a thickness of 2.3 mm. The current is induced in the small bore-pipe using the coil, and is distorted around the discontinuous area that is damaged. The magnetic field that is due to the existence of damage is affected by the sensor arrays. By scanning the arrayed magnetic sensors in the axis direction to the specimen, the eddy current images can be obtained. To verify the proposed method, we applied the proposed method to three 9Cr-1Mo small-bore pipe specimens with the following degrees of damage: (1) circumferential grooves with a width of 7.94 mm and a depth of 5–40%, (2) one-side flaws with a length of 69.2 mm and a depth of 30–60% on the 90°area, and (3) one-side flaws with a width of 7.94 mm and a depth of 5–40% on the 180° area. The results show the following damages: (a) 20% groove, (b) 30% one-side flaw on the 90° area, and (c) 30% one-side flaw on the 180° area, as shown in Figure 1.

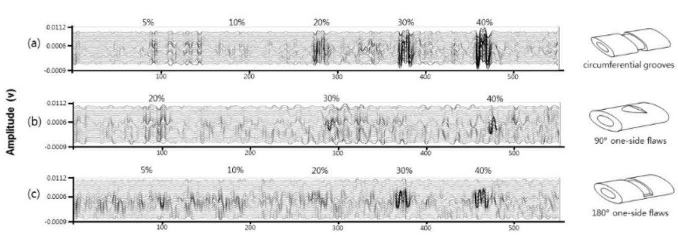

Figure 1. Experimental results: (a) circumferential grooves, (b) 90° one-side flaws, (c) 180° one-side flaws.

Database Generation and Exploitation for Efficient and Intensive Simulation Studies

---**R. Miorelli**, X. Artusi, and C. Reboud, CEA LIST, Departement Imagerie et Simulation pour le Controle, Gif-sur-Yvette, 91191, France

---In the field of non-destructive evaluation, numerical simulation tools are commonly used to carry out studies aiming to define the inspections procedures, perform statistical studies or optimize particular problems. Among the main topics of interest, one can cite Model Assisted Probability Of Detection (MAPOD) [1,2], parametric studies for sensor design, sensitivity analysis and optimization, generally speaking, in terms of inversion procedures [3]. All these applications require a very large set of simulations in order to gather a good amount of information needed to reach meaningful conclusions. Furthermore, due to the complexity of the addressed problems, simulation campaigns very often turn to be too consuming in terms of computational burden. A way to mitigate such computational cost is to pass through the concept of the Design of Experiments (DoE). DoE aims at replacing a forward solver by a suitable and computationally- cheap metamodel (also called surrogate model) [3], which is an almost real-time substitute to the "real" model within a certain validity domain. Metamodel generation relies first on the construction of a suitable database collecting a set of real-model results. This step is considered to be the off-line part of the generation process and it embeds almost all the computational burden of the approach. The second metamodel component is an adapted and almost real-time interpolator which is employed to replace the forward solver within the database variation range. In this paper, we first present a database generation approach and its exploitation through different kind of interpolators (meshless or mesh-based ones). In the proposed approach, the database generation, has been performed by focusing our attention on the parsimony in terms of number of samples required for the database generation. In this way, an adaptive approach has been applied and evaluated with respect to more classical database generation fixed-schema like full-factorial design, Latin hypercube sampling etc. In a second part of this paper, the metamodel-based approach is applied to perform computationally-expensive studies like: MAPOD studies [1,2], sensitivity analyses and parametric inversion problems [3]. Even though the examples proposed in this paper are focused on Eddy Current Testing (ECT) simulation problems, the concept of database generation and its exploitation as well as the considerations around the studies presented are still valid, regardless the physics considered and the forward solver employed for generating the database.

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<u>**Electromagnetic and Eddy Currents**</u>

Further Capacitive Imaging Experiments Using Modified Probes

---**Xiaokang Yin**, An Yan, Zhen Li, Wei Li, and Guoming Chen, China University of Petroleum (East China), Centre for Offshore Equipment and Safety Technology, Qingdao 266580, China; David A. Hutchins, Warwick University, School of Engineering, Coventry CV4 7AL, United Kingdom

---In recent years, capacitive imaging (CI) is growing in popularity within the NDE communities, as it has the potential to test materials and structures for defects that are not easily tested by other techniques. In previous work, The CI technique has been successfully used on a various types of materials, including concrete, glass/carbon fibre composite, steel, etc. In such CI experiments, the probes are normally with symmetric or concentric electrodes etched onto PCBs. In addition to these conventional coplanar PCB probes, modified geometries can be made and they can lead to different applications. A brief overview of these modified probes, including high resolution surface imaging probe, combined CI/eddy current probe, and CI probe using an oscilloscope probe as the sensing electrode, is presented in this work. The potential applications brought by these probes are also discussed.**---**This work was supported by the Natural Science Foundation of China (No. 51205412), the China Postdoctoral Science Foundation (No. 2013M540568 and No. 2014T70666), the Scientific and Technological Developing Project of Shandong province (No.2013GHY11513).

Application of Metal Magnetic Memory Technology on Jack-Up Platform

---**Changhang Xu**, Liping Cheng, Gang Wang, Guoming Chen, and Jing Xie, China University of Petroleum, Center for Offshore Engineering and Safety Technology, Qingdao, 266580, China

---Metal magnetic memory test (MMMT), which is an effective way in evaluating early damages of ferrimagnets, can determine the existence of material stresses concentration and premature defects. As one of offshore oil exploration and development equipment, jack-up platform always generate stress concentration during its life-cycle due to complicated loading condition and the hash marine environment, which will decline the bearing capacity and cause serious consequences. The paper applying MMMT to detect defects in some key structures of jack-up platform including legs with welded joints, deck, crane hook and cantilever beam. The signals acquired by MMM-System are processed for feature extracting to evaluate the severity of structure stress concentration. The results show that the method presented in this paper based on MMMT can provide an effective way of defect detection and structural health monitoring for Jack-up Platform.

Microwave and MM Wave

Microwave and Millimeter Wave High-Resolution Imaging of Fiberglass Composites

---Mohammad T. Ghasr, Matthew J. Horst, and **R. Zoughi**, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Missouri University of Science and Technology (S&T), Rolla, MO 65409; Mario Lechuga, R. Rapoza, and C. Renoud, Fiberglass Structural Engineering (FSE), Inc., Bellingham, WA 98226

---Microwave and millimeter wave signals span the frequency range of 30 GHz to 300 GHz, corresponding to a wavelength range of 10 mm to 1 mm. Signals at these frequencies can easily penetrate inside dielectric composites and interact with their inner structures [1]. The relatively small wavelengths and wide bandwidths associated with these signals enable production of high spatial-resolution images of materials and structures. Incorporating imaging techniques such as synthetic aperture focusing and holographical methods, based on robust back-propagation algorithms, have shown tremendous potential for real-life structural health monitoring applications [2, 3]. These imaging techniques, in conjunction with several high-resolution, real-time and portable imaging systems, have been successfully applied for wide range of critical nondestructive testing (NDT) applications [4]. Fiberglass is increasingly used for a number of applications involving chemical storage and transport (i.e., tanks and pipes). From a composite structure point-of-view, fiberglass structures vary in the degree of structural complexity and undergo structural deterioration while in service. Microwave and millimeter wave high-resolution imaging techniques are well-suited for one-sided and rapid imaging of such structures. These types of images render information about the spatial extent and severity of damage. In addition, these system can be made into an array system enabling rapid imaging a structure by following curvatures as well. In this presentation, the fundamental foundation of these imaging techniques is presented, along with several specific examples of imaging fiberglass composite samples with internal damage.

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Vision/Optical/Thermal

Effect of Vibrational Behavior on Frictional Heating Mechanism in Vibrothermography

---**Wonjae Choi**[1*], Manyong Choi[1], Jeounghak Park[1], and Kooahn Kwon[2], [1]KRISS, Center for Safety Measurement, 267 Gajeong-Ro, Yuseong-Gu, Daejeon 305-340, Republic of Korea; [2]University of Science & Technology, Department of Aerospace System, 217 Gajeong-Ro, Yuseong-Gu, Daejeon 305-350, Republic of Korea

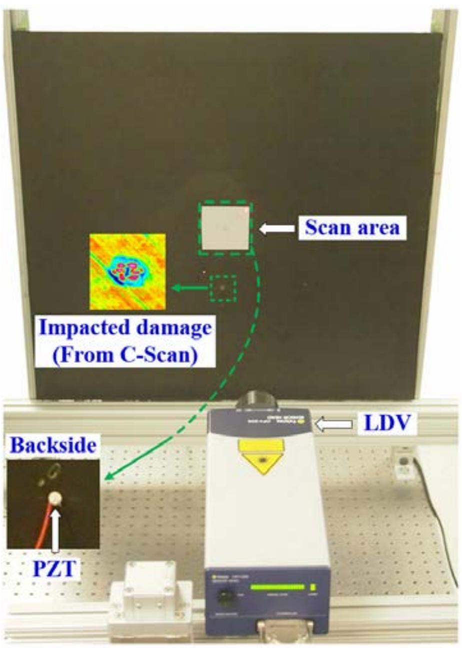
---In vibrothermography, vibration energy given to a structure inspected is transferred into heat energy at defects, and then infrared camera is used to inspect the structure by detecting the heat profile. The vibrothermography has been increasingly studied as an advanced NDE inspection method due to its advantages such as wide coverage range and image producing and non-contact feature. Friction is known to be a major cause of the heating at cracks, although there are several other candidates such as plastic deformation and thermoelastic effect. The heating mechanism is difficult to investigate quantitatively since the accessibility of the actual heating site is limited in experiments. Numerical simulation has been conducted to overcome this limits, but is also challenging because it requires to solve vibration-heat multi-physics problem with nonlinear contact in three-dimensional structures. In this paper, the frictional heating mechanism is investigated in terms of vibration behavior of a specimen and a target crack in it. Three dimensional numerical simulations are conducted for different excitation cases and the results are discussed.**---**This work was supported by National Agenda Project (NAP) funded by Korea Research Council of Fundamental Science & Technology

Structural Health Monitoring

A 2-D Areal Scan for Imaging Composite Damage Using an Enhanced CCRTM Technique

---**Jiaze He**[1,2], Fuh-Gwo Yuan[1,2], [1]Center for Integrated Structural Health Management, National Institute of Aerospace, Hampton, VA 23666; [2]Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695

---This poster presents a two-dimensional (2-D) non-contact areal scan system to image and quantify impacted damage in a composite plate using an enhanced zero-lag cross-correlation reverse-time migration (E-CCRTM) technique. The system comprises a single piezoelectric actuator mounted onto the composite plate and a laser Doppler vibrometer (LDV) for scanning a region for capturing the scattered wavefield in the vicinity of the PZT. The proposed damage imaging technique takes into account the amplitude, phase, geometric spreading, and all the frequency content of the Lamb waves propagating in the plate, thus, the reflectivity coefficients of the delamination can be calculated and potentially be related to damage severity. Comparisons are made in terms of damage imaging quality between 2-D areal scans and linear scans as well as between the proposed and existing imaging conditions. The experimental results show that the 2-D E-CCRTM has robust performance to image and quantify impacted damage in large-scale composites using a single PZT actuator with a nearby areal scan using LDV.



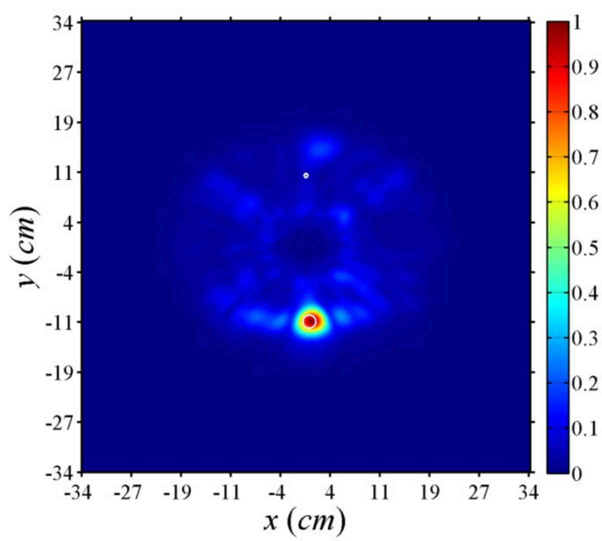


Figure 1. Hybrid PZT/LDV scanning system. Figure 2. Damage imaging using 2D E-CCRTM.

Session 32

SESSION 32

X-RAY, CT, AND RADIOGRAPHIC METHODS II

Uwe Ewert and Joseph N. Gray, Co-Chairpersons
Lakeshore A

3:30 PM **Characterization of Pores in High Pressure Die Cast Aluminum Using Active Thermography and Computed Tomography**
---Christiane Maierhofer, Philipp Myrach, Mathias Röllig, **Florian Jonietz**, Bernhard Illerhaus, and Dietmar Meinel, BAM Bundesanstalt für Materialforschung und –prüfung, Berlin, Germany; Uwe Richter, Technical University of Freiberg, Freiberg, Germany; Ronald Miksche, University of Applied Sciences, Dresden, Germany

3:50 PM **Blind Beam-Hardening Correction from Poisson Measurements**
---**Renliang Gu** and Aleksandar Dogandzic, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:10 PM **MOVED FROM SESSION 31 - Applications of an X-Ray NDE Simulation (XRSIM) for Developing and Optimizing Inspection Protocal for Aerospace Components—A Case Study**
---**S. Singh**[1] and J. Gray[2], [1]Honeywell International, Inc., 110 S. 34th Street, M/S 503-118, Phoenix, AZ 85034; [2]Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:30 PM **MOVED FROM SESSION 27 - Multi-Scale X-Ray Romography for Advanced Packaging: From Micro to Nano**
---**Ehrenfried Zschech**[1,2], Markus Loeffler[2], Juergen Gluch[1], [1]Fraunhofer IKTS-MD Dresden, Germany; [2]Technische Universität Dresden, Dresden Center for Nanoanalysis (DCN) and Center for Advancing Electronics Dresden (cfaed), Germany

4:50 PM **Quantum Dots Microstructured Optical Fiber for X-Ray Detection**
---**S. L. DeHaven**, P. A. Williams, and E. R. Burke, NASA Langley Research Center, Mail Stop 231, Hampton, VA 23681

3:30 PM

Characterization of Pores in High Pressure Die Cast Aluminum Using Active Thermography and Computed Tomography

---Christiane Maierhofer, Philipp Myrach, Mathias Röllig, **Florian Jonietz**, Bernhard Illerhaus, and Dietmar Meinel, BAM Bundesanstalt für Materialforschung und –prüfung, Berlin, Germany; Uwe Richter, Technical University of Freiberg, Freiberg, Germany; Ronald Miksche, University of Applied Sciences, Dresden, Germany

---Larger high pressure die castings and decreasing wall thicknesses are raising the issue of casting defects like pores. Furthermore, in thinner structures these defects have a higher influence on the properties of the components. Therefore, non-destructive testing methods are required which enable a fast and efficient quality assurance. Here, active thermography may be a well suited method enabling a complete contactless, fast and efficient data recording and processing when using optimized excitation sources, like flash lamps, halogen lamps, lasers or LED arrays. As the penetration depth of the method is limited by the thermal diffusion processes, the method should be applied preferably to thin structures. Up to now, systematic porosity investigations with active thermography have only been performed in CFRP structures [1] or during welding of aluminum alloy [2]. The feasibility of active thermography using flash and periodic lockin excitation for detecting delamination in copper joints has already been proven [3]. But more systematic studies are required concerning the quantitative assessment of porosity in metals with high thermal diffusivity. Therefore, in this presentation numerical simulation will demonstrate the feasibility to detect flat bottom holes in aluminum test specimens using active thermography with flash excitation. These simulations have been proven experimentally. Finally, active thermography has been applied to an aluminum sample containing real pores, while these data have been validated using computed tomography. Figure 1 displays thermograms recorded from the front and the rear side of the real test specimen showing pores and pore clusters with a diameter of up to 6 mm as hot spots. This specimen has also been investigated with computed tomography, and three cross sections of the specimen show that the positions of the larger pores correspond to the hot spots in the thermograms. The requirements and limits of active thermography using flash excitation are analyzed and future studies using periodic heating with a widened laser beam will be discussed.

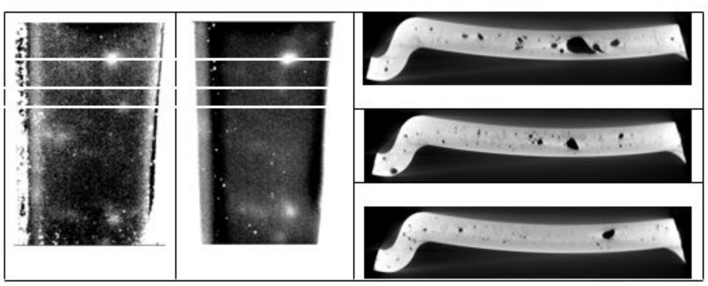


Figure 1. Left and middle: Thermograms recorded from the front side (left) and from the rear side (middle) of the sample 40 ms after the flash. Right: Tomograms showing the cross sections along the lines drawn in the thermograms. The sample has a length of 150 mm, a width of up to 50 mm and a thickness of 4.3 mm. The images are not true to scale.

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3:50 PM

Blind Beam-Hardening Correction from Poisson Measurements

---**Renliang Gu** and Aleksandar Dogandzic, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

We develop a sparse image reconstruction method for Poisson-distributed polychromatic X-ray CT measurements under the blind scenario where the material of the inspected object and the incident energy spectrum are unknown. To obtain a parsimonious mean measurement-model parameterization, we first rewrite the measurement equation by changing the integral variable from photon energy to mass attenuation, which allows us to combine the variations brought by the unknown incident spectrum and mass attenuation into a single unknown mass-attenuation spectrum function; the resulting measurement equation has the Laplace integral form. The mass-attenuation spectrum is then expanded into basis functions using a B-spline basis of order one. We develop a block coordinate-descent algorithm for constrained minimization of a penalized negative Poisson log-likelihood cost function, where constraints and penalty terms ensure nonnegativity of the spline coefficients and nonnegativity and sparsity of the density map image. This algorithm alternates between a Nesterov's proximal-gradient (NPG) step for estimating the density map image and a limited-memory Broyden–Fletcher–Goldfarb–Shanno with box constraints (L-BFGS-B) step for estimating the incident-spectrum parameters. To accelerate convergence of the density-map NPG steps, we apply a step-size selection scheme that accounts for varying local Lipschitz constants of the objective function. Real X-ray CT reconstruction examples demonstrate the performance of the proposed scheme.

4:10 PM

Application of NDE Simulation, XRSIM, to Inspection Design and Optimization

---S. Singh[1] and J. Gray[2], [1]Honeywell International, Inc., 110 S. 34th Street, M/S 503-118, Phoenix, AZ 85034; [2]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Faced with schedule demands and cost pressures, NDE Engineers are exploring ways for meeting schedule and reducing cost by integrating inspections with design and manufacturing by leveraging NDE simulation whenever there is an opportunity. NDE simulation modeling and analysis offers productivity tools for an NDE Engineer in much the same manner as the Computer Aided Design (CAD) tools to draftsmen for increasing productivity. Simulation enables NDE engineers to expand the use of physics-based models to predict inspection coverage for complex aerospace components and structures, and thereby providing reliable assessments of the location and extent of damage. All of these has been achieved by deploying NDE simulators in a production environment wherein a large number of inspection trials engaging a range of equipments not available at a particular site and the use of realistic defect geometry representative of the damage processes. The defects in a particular application placed at any locations with varying size and orientation in a part can be used for determination of optimal coverage in the part at known inspection sensitivity. Of the dozens of parameters effecting images quality, one can use a simulation tool to identify the 2-4 key parameters that offers the optimized techniques for maximum inspection coverage at the highest sensitivity. For example, the simulation tools allow for rapid and cost effective evaluation of the trade-off of competing parameters, such as KV, time of exposure, and amperage for inspecting the part. In this case study, we will demonstrate the applications of NDE simulation for commercial turbine blade and engine mount. These findings will also be compared to experimental results with estimates of difference in the two approaches, namely experimental and simulation, in terms of time and coverage map. The study aims in demonstrating the use of NDE simulation (XRSIM) for reducing the time and cost of the analyses that are required to determine quantities such as POD (Probability of Detection) curves.

Keywords: NDE, X-ray simulation, XRSIM, optimization

4:30 PM

Multi-Scale X-ray Tomography for Advanced Packaging: From Micro to Nano

---**Ehrenfried Zschech**[1,2], Markus Loeffler[2], Juergen Gluch[1], [1]Fraunhofer IKTS-MD Dresden, Germany; [2]Technische Universität Dresden, Dresden Center for Nanoanalysis (DCN) and Center for Advancing Electronics Dresden (cfaed), Germany

---Advanced packaging, including 3D IC integration, is one of the main drivers in packaging and system integration to meet the requirements for miniaturized smart systems with high functionality and high performance. For 3D through-silicon-via (TSV) stacking of wafers or dies, die-to-die interconnections like micro solder bumps (e.g. AgSn) and Cu pillars are used. Figure 1 (left) shows a stack with a TSV interposer structure [1]. 3D TSV integration technologies and the resulting 3D-stacked products challenge materials and process characterization. The control of the TSV filling and micro-bump quality is a particular issue. Several NDE techniques for metrology and failure analysis are currently under discussion. In this paper, the potential and the limits of sub-micron XCT and nano XCT for NDE of 3D TSV stacks are described. It is shown that a multi-scale approach, i.e. using imaging techniques with several resolution ranges, is necessary for these particular tasks. Since sub-micron XCT (resolution about 700 nm) and nano XCT (resolution about 50 nm) are very useful lab-based techniques with a promising prospect for the future. We demonstrate the capabilities for nondestructive imaging of multi-die stacks with Cu TSVs and AgSn micro solder bumps. Figure 1 (center) demonstrates sub-micron XCT study of such a multi-die stack. TSV etch profiles and major filling defects in TSVs (small voids in Cu TSVs) are clearly visualized. An analysis of individual bumps reveals mismatches in relative positioning, variability in the shape, micron-size pores, and the distribution of intermetallic phases. This information is important to evaluate the respective process steps (process control) and the product reliability (quality control). Since deviations from the targeted geometry and defects are difficult to locate precisely from a two-dimensional image, X-ray computed tomography has to be applied. Nano XCT studies at Cu TSVs show in particular, that small voids in Cu TSV with a size of about 100 nm can be visualized. Figure 1 (right) shows virtual cross-sections through a Cu-TSV based on a (nondestructive) nano XCT study. Voids in the range of 100 nm are clearly visible. After identifying the voids, a more detailed (destructive) SEM/FIB study provides complementary information regarding the root cause of the voids.

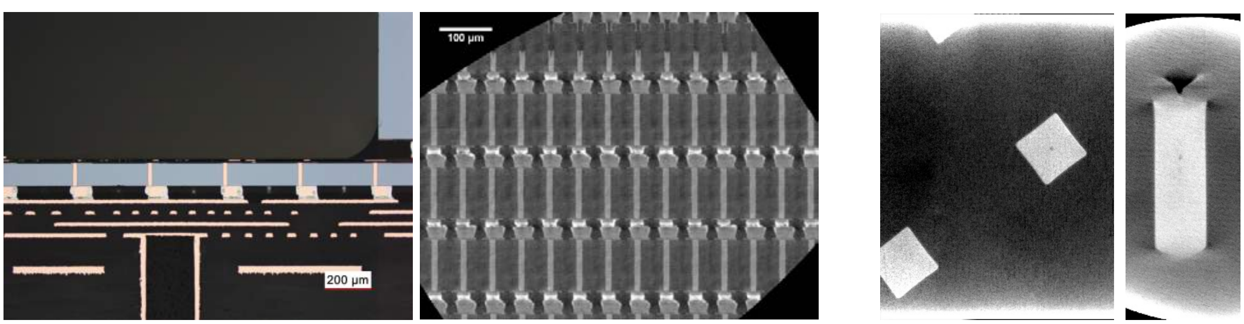

Figure 1. From left to right: 2.5D stack with TSV interposer structure, Virtual cut through 3D stack with Cu TSVs and AgSn micro solder bumps (micro XCT study) – TSV filling defects and micro-bump issues, Visualization of filling defects (voids) in the center of a TSV (nano XCT study, virtual horizontal and vertical cross-sections) [1].

Reference

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4:50 PM

Quantum Dots Microstructured Optical Fiber for X-Ray Detection

---**S. L. DeHaven**, P.A. Williams, and E. R. Burke, NASA Langley Research Center, Mail Stop 231, Hampton, VA 23681

---A novel concept for detection of x-rays with microstructured optical fibers containing quantum dots scintillation material comprised of zinc sulfide nano crystals doped with magnesium sulfide is presented. These quantum dots are applied inside the microstructured optical fibers using capillary action. The x-ray photon counts of these fibers are compared to the output of a collimated CdTe solid state detector over an energy range from 10 to 40 keV. The results of the fiber light output and associated effects of an acrylate coating and the quantum dot application technique are discussed.

Session 33

SESSION 33

PIPELINES AND AUTOMATION

Don Palmer and Tom Batzinger, Chairpersons
Nicollet D1

3:30 PM **WITHDRAWN - The Impact of Automation and Robotics on Industrial NDE**
---**Donald D. Palmer, Jr.**, Boeing Research & Technology, 5775 Campus Parkway, Bldg. 270A, Room 308, MC S270-3800, Hazelwood, MO 63042

3:50 PM **Automated XML-Based Experiment Logging Increases Throughput and Reduces Errors in Hybrid Manual/Automatic Procedures**
---**Stephen D. Holland** and Tyler Lesthaeghe, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, Ames, IA 50014

4:10 PM **Object Motion Tracking in the NDE Laboratory by Random Sample Iterative Closest Point**
---**Rafael Radkowski**, David Wehr, Elizabeth Gregory, and Stephen D. Holland, Iowa State University, Virtual Reality Applications Center and Center for Nondestructive Evaluation, Ames, IA 50011

4:30 PM **Evaluating an SH Wave EMAT System for Pipeline Screening and Extending into Quantitative Defect Measurements**
---**M. Clough** and S. Dixon, University of Warwick, Physics Department, Gibbet Hill Road, Coventry CV4 7AL, United Kingdom; M. Fleming and M. Stone, Sonomatic Ltd., Dornoch House, The Links, Birchwood, Warrington, Cheshire, WA3 7PB, United Kingdom

4:50 PM **Current Deflection NDE for Pipeline Inspection and Monitoring**
---**Rollo Jarvis** and Peter Cawley, Imperial College London, Department of NDE, London, United Kingdom; Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, Ohio 45221

5:10 PM **Material Property Relationships for Pipeline Steels and the Potential for Application of NDE**
---**Lucinda J. Smart** and Leonard J. Bond, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

3:30 PM

Automated XML-based Experiment Logging Increases Throughput and Reduces Errors in Hybrid Manual/Automatic Procedures

---**Stephen D. Holland** and Tyler Lesthaeghe, Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50014

---Even as we build more and more sophisticated measurement systems with more and more interconnected components, some process steps remain inevitably manual. We describe the use and benefits of integrating checklist-based XML-based experiment logging into an NDE research laboratory environment. Errors were reduced by an order of magnitude and throughput likewise increased by an order of magnitude. The resulting experiment log has more consistent, better structured information with crosslinks to checklist records and bulk data. It is readily interpretable as a log, as a table, or in a custom-defined view. The software tools involved are intended to be published as open-source software. Besides the throughput and error reduction benefits, using tools such as these to store laboratory data as semi-structured XML makes the _les both human- and computer-readable and allows more robust processing and analysis workflows. XML provides a hierarchical representation that can be isomorphic to the hierarchy of the underlying measurements: An experiment can consist of a series of measurements, each of which can have sub-measurements. Also, almost any sort of document can be represented in XML and many common formats already are XML-based. Storing our laboratory data as XML allows us to take advantage of the rich libraries of tools for manipulating and transforming XML documents, and take advantage of existing standards for markup and metadata and build off of those tools too. Working in XML will make it easier for academic researchers to comply with increasing demands for open sharing of publically funded data, and for industrial researchers to facilitate enterprise-wide interoperability of diverse systems.---This material is based on work supported by the Air Force Research Laboratory under Contract #FA8650-10-D-5210, Task Order #023 and performed at Iowa State University Case Number 88ABW-2015-2521

3:50 PM

Object Motion Tracking in the NDE Laboratory by Random Sample Iterative Closest Point

---**Rafael Radkowski**, David Wehr, Elizabeth Gregory, and Stephen D. Holland, Iowa State University, Virtual Reality Applications Center and Center for Nondestructive Evaluation, Ames, IA 50011

---We present a computationally efficient technique for real-time motion tracking in the NDE laboratory. The technique relies on a random sample consensus (RANSAC) solution to the iterative closest point (ICP) problem for identifying object shapes [1, 2]. Object shapes can be different specimens and fixtures. This process will be useful in the NDE laboratory because it provides a mean to automatically register recorded NDE data to a 3D part model. Specimens can be manually aligned at any test stand, the position and orientation of every a-priori known shape can be computed and forwarded to the data management software. The object motion tracking process is indicated in Figure 1, the example shows a composite material specimen at the thermography test stand.

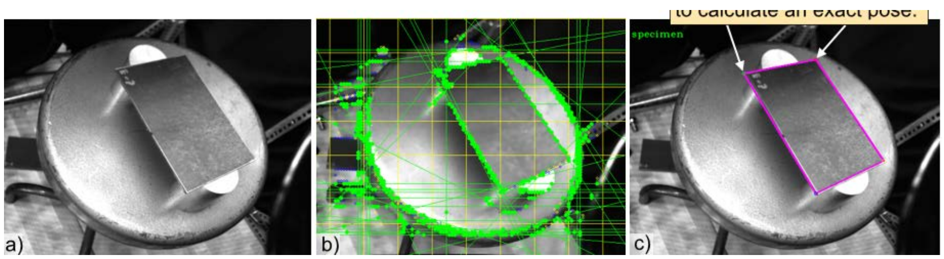

Figure 1. Motion tracking, a) a composite specimen prepared for an experiment, b) points along edges are extracted to identify the specimen, c) the corners of the specimen are detected with high fidelity to calculate its position and orientation of the specimen.

We first search for edges along scan lines to find points along object edges (Fig. 1b). Those points are considered as a 2D point cloud. To find an object shape, we first select a minimum set of random starting points, then, second, align a reference shape to the starting points using the ICP algorithm. These two steps are repeated until convergence. The result is a set of points which match the reference shape best. Next, the corner points of this point set are identified (Fig 1c) to calculate the object's position and orientation. The result is the ability to track objects based on a sequence of live camera images. This approach is robust against outliers and yields accurate position and orientation data. We will introduce the use case at the NDE laboratory, the tracking method, recognition results (true-positive / false-positive), and the accuracy of the position and orientation estimation.

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4:10 PM

Evaluating an SH Wave EMAT System for Pipeline Screening and Extending into Quantitative Defect Measurements

---**M. Clough** and S. Dixon, University of Warwick, Physics Department, Gibbet Hill Road, Coventry CV4 7AL, United Kingdom; M. Fleming and M. Stone, Sonomatic Ltd., Dornoch House, The Links, Birchwood, Warrington, Cheshire, WA3 7PB, United Kingdom

---Guided waves are now commonly used in industrial NDT for locating corrosion in pipelines in the form of wall thinning. Shear Horizontal waves generated by EMATs are used in a screening arrangement to locate and size corrosion in terms of axial extent and circumferential positioning. This is facilitated by propagating SH waves circumferentially around the pipeline whilst moving a scanning rig axially, keeping transducer separation constant. This arrangement is preferential in that it can operate through thin(up to 1mm) coatings and does not require full access to the pipe's circumference and is useful for detecting corrosion in difficult to access regions such as below pipe supports and in subsea applications. The performance of the system in terms of screening capability and the possibilities of extension into more quantitative measures are assessed. The behavior of different wave modes as they interact with defects is investigated via experimental measurements on artificially induced corrosion patches and measurements on samples with in service corrosion. Measurement of the axial extent of corrosion patches, circumferential positioning and a range of possible remaining thickness is assessed. Finite element modelling of SH mode interaction with defects is used to identify what happens to different wave modes when they interact with defects in terms of reflection, diffraction and mode conversion.---The work is funded by EPSRC through an EngD studentship from the Research Centre for Non Destructive Evaluation and supported by Sonomatic Ltd.

4:30 PM

Current Deflection NDE for Pipeline Inspection and Monitoring

---**Rollo Jarvis** and Peter Cawley, Imperial College London, Department of NDE, London, United Kingdom; Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, Ohio 45221

---Failure of oil and gas pipelines can often be catastrophic therefore routine inspection for time dependent degradation is essential. In-Line Inspection (ILI) is the most common method used; however, this requires the insertion and retrieval of an inspection tool that travels through the pipe and risks becoming stuck. Furthermore, design limitations of many pipes prevent the use of ILI therefore alternative external methods must be employed. Many NDE techniques suffer greatly reduced sensitivity at significant standoff and therefore necessitate the often unfeasible removal of pipe insulation coating. The application of an NDE technique relying on injecting an electric current along the pipe and indirectly measuring the deflection of this current around defects for detection or monitoring purposes is being investigated. This is achieved by measuring changes in orthogonal components of the induced magnetic flux density outside of pipe insulation coating. A Finite Element (FE) model has been developed that allows the prediction of the perturbations in magnetic flux density caused by current deflection. An array of three orthogonally oriented Anisotropic Magnetoresistive (AMR) sensors has been used to measure the components of the magnetic flux density surrounding a 6” schedule-40 pipe carrying 2 A axial current. The results have allowed validation of the FE model. Measurements of the magnetic flux density at 50 mm standoff are repeatable to around 50 pT which is a promising result for the prospect of structural health monitoring (SHM). Magnetic signals are incurred by normal changes in the wall thickness of the pipe due to manufacturing tolerances which must be corrected for using baseline subtraction in order to optimise the sensitivity to defects. Array configurations have been proposed for the use of magnetic sensors in a scanning technique that functions outside of insulation coating to screen for defects, and for SHM where corrosion hotspots may be monitored for defect growth. Additionally, parametric FE studies have been completed that predict the signals from different defect geometries.

4:50 PM

Material Property Relationships for Pipeline Steels and the Potential for Application of NDE
---Lucinda J. Smart and Leonard J. Bond, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011
---The oil and gas industry in the USA has an aging infrastructure of pipelines, 70% of which were installed prior to 1980, with almost half being installed during the 1950s and 1960s. As this system continues to age, there is growing interest in safety and knowledge of pipe properties so that a safe operating pressure can be determined. (Nanney, 2013) Current ILI technologies focus on defect detection and characterization, such as corrosion, cracking, and the probability of detection. As a part of the assessment process it is necessary to know the pipe properties to determine failure limits based on defects. The mechanical properties (yield strength, tensile strength, transition temperature, and fracture toughness) of steel pipe must be known in order to respond to defects in an appropriate manner. Material property measurements such as hardness, chemical content, grain size, and microstructure may be important in determining the mechanical properties of steel pipe short of performing cut-outs of the physical pipes for destructive tests. Current nondestructive methods of inspection do not fully define these properties, so destructive testing must be performed, which is costly, time-consuming, and many times not practical for pipe that is in-service. There are in-ditch methods of inspection that can determine many material properties, and there is potential for determination of some mechanical properties. Neither current methods nor the ILI inspection data have yet determined the mechanical properties desired with the confidence of destructive testing. In the quest to obtain the mechanical properties of a steel pipe using a nondestructive method, it is important to understand there are many inter-related variables. Manufacturing processes have changed significantly over the past century, resulting in significant differences in pipe with the same properties, particularly noticeable with the alloying elements present in more modern pipe. Advancements in inspection technologies and the data able to be obtained by current technologies is currently being explored by several interested parties. (Nestleroth & Haines, 2013). In-line inspection (ILI) companies are specifically focusing on the magnetic measurements from eddy current and magnetic flux leakage measurements to relate those to mechanical properties. (Belanger & Barker, 2014). ILI also regularly uses ultrasound measurements for wall thickness determination, and the potential application of advancement in ultrasound measurements for grain size and other properties are being explored. This paper reports a literature review and an analysis of a sample set of data. There is promise for correlating the results of NDE measurement modalities to the information required to develop relationships between those measurements and the mechanical measurements desired of pipelines to ensure proper response to defects which are of significant threat.---This work was supported by Kiefner, ApplusRTD, Pacific Gas and Electric, and the Center for Nondestructive Evaluation.

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Session 34

SESSION 34
UT MICROSTRUCTURAL SCATTERING
Joe Turner and Paul Panetta, Co-Chairpersons
Nicollet D2

3:30 PM **Acoustoelastic Theory of Grain Scattering and Attenuation**
---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, Lincoln NE 68588

3:50 PM **Ultrasonic Scattering Model Based on the Self-Consistent Effective Medium of Polycrystals**
---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, Lincoln NE 68588

4:10 PM **Finite Element Modelling of Wave Propagation in Highly Scattering Materials**
---**A. Van Pamel**, P. Huthwaite, C. Brett, and M. Lowe, Imperial College London, Mechanical Engineering Department, South Kensington Campus, London, SW7 2AZ, United Kingdom

4:30 PM **Grain Scattering Measurements Using Cylindrically Focused Immersion Transducers at Normal Incidence**
---**Andrea Arguelles**, Christopher M. Kube, and Joseph A. Turner, University of Nebraska-Lincoln, Mechanical and Materials Engineering, W342 Nebraska Hall, Lincoln, NE, 68588

4:50 PM **Mode-Converted Diffuse Ultrasonic Backscatter of Elongated Grains**
---**Ping Hu**, Andrea Arguelles, Christopher M. Kube, and Joseph A. Turner, University of Nebraska-Lincoln, Mechanical and Materials Engineering, W342 Nebraska Hall, Lincoln, NE 68588

5:10 PM **Contribution of Double Scattering for Diffuse Ultrasonic Backscatter Measurements on Nickel Alloys**
---Nathanial Matz[1], Ping Hu[1], Sandra Dugan[2], and **Joseph A. Turner**[1], [1]Mechanical and Materials Engineering, University of Nebraska-Lincoln, W342 Nebraska Hall, Lincoln, NE, 68588, [2]Abteilung ZfP im Anlagen- und Maschinenbau, Materialprüfungsanstalt Universität Stuttgart (MPA), Pfaffenwaldring 32, 70569 Stuttgart, Germany

5:30 PM **Ultrasonic Scattering Measurements of Grain Size and Shape in Nickel and Titanium Alloys with Elongated Grains**
--**Paul D. Panetta**[1], Dale McElhone[1], Hualong Du[2], and Waled Hassan[3,] [1]Applied Research Associates, Inc., 1206 Great Road Gloucester Point, VA 23062, [2]now at North Carolina State University, Department of Mechanical and Aerospace Engineering, 911 Oval Drive, Raleigh, NC 27695,[3] Rolls-Royce Corporation, 546 South Meridian Street, Indianapolis, IN 46225

3:30 PM

Acoustoelastic Theory of Grain Scattering and Attenuation

---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, Lincoln NE 68588

---Acoustoelasticity has traditionally been used to define the phase velocity of an elastic wave propagating in a stressed material. In metals, the elastic wave propagates through an aggregate of grains where each grain has unique elastic properties due to different orientations of the grain's crystallite axes. These point-to-point differences in the elastic properties lead to scattering and dispersion effects of the coherent wave. Previous acoustoelastic models have attempted to model the coherent wave by averaging the elastic properties of the individual grains. However, the point-to-point elastic differences between grains in a stressed metal has not been considered previously. A new model of acoustoelasticity including grain scattering effects is presented. The evaluation of the model indicates that material stresses have a strong influence on the scattering and attenuation of the coherent wave for various propagation and wave polarizations. Example results of stress-dependent longitudinal and shear grain scattering and attenuation coefficients are presented for polycrystalline iron and aluminum. The steps toward practical application for NDT stress measurements will be outlined and discussed.

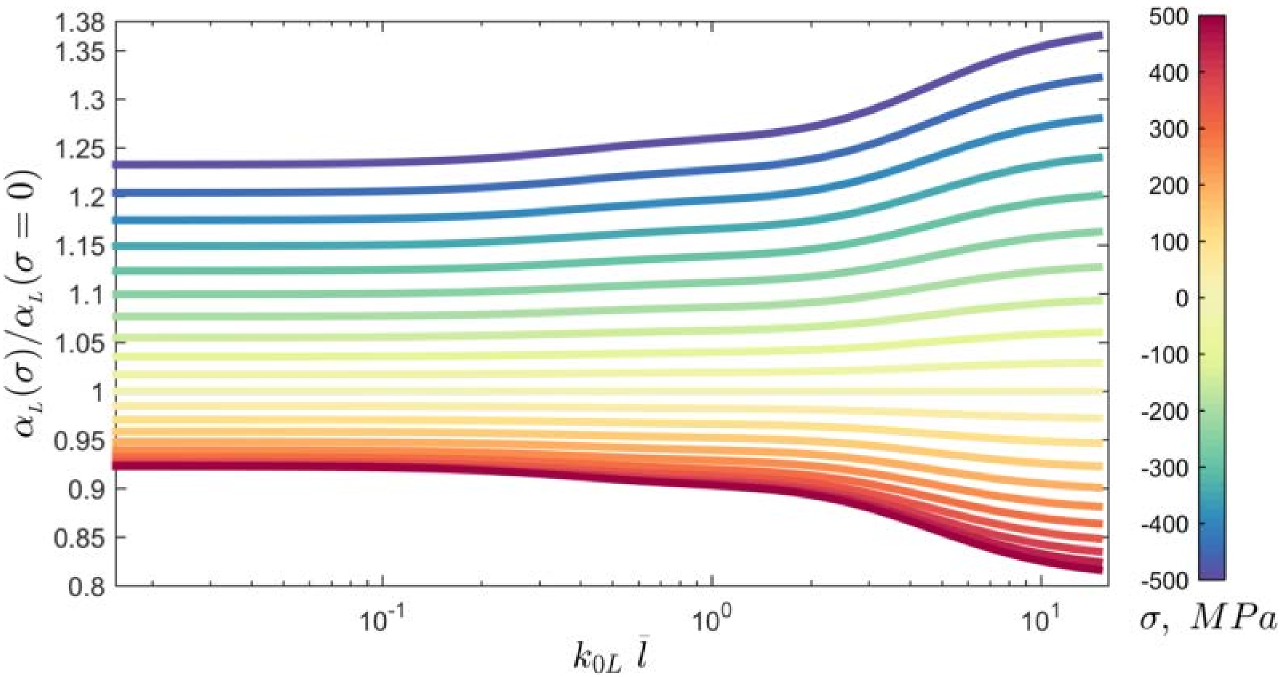

Figure 1. The stress dependence of the longitudinal wave attenuation coefficient for propagation in the direction of uniaxial stress. The x-axis variable is dimensionless wave numbers where the stress-dependency of the attenuation is shown to be a function of wave number and grain radius.

3:50 PM

Ultrasonic Scattering Model Based on the Self-Consistent Effective Medium of Polycrystals

---**Christopher M. Kube** and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, Lincoln NE 68588

---The self-consistent method of averaging elastic moduli to define the effective medium of a polycrystal is used to investigate the dynamic problem of wave propagation. An alternative covariance tensor that describes the elastic moduli fluctuations of the polycrystal containing self-consistent elastic properties is derived and is significantly smaller than the covariance tensor formed through traditional Voigt averaging. Attenuation curves are generated using the self-consistent elastic moduli and covariance tensors and these results are compared with previous Voigt averaged estimates. The second-order polycrystalline dispersion relation for the self-consistent scheme is presented for cases of low and high crystallite anisotropy. The attenuation coefficients and dispersion relations derived through the self-consistent scheme are considerably different than previous estimates. Strong agreement exists between the longitudinal attenuation coefficient of copper and experimental measurements [1].

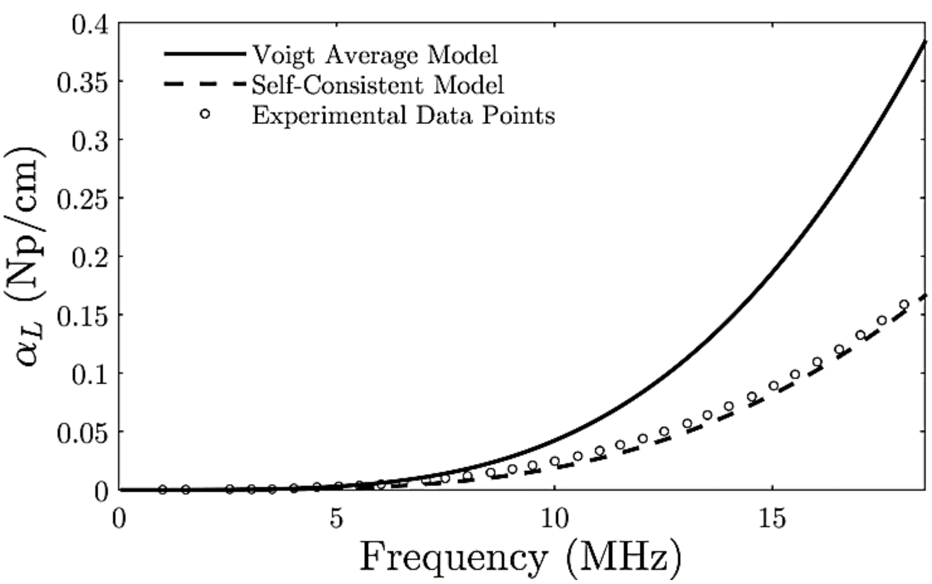

Figure 1. Theoretical attenuation coefficients of a longitudinal wave in copper are compared to experimental data points [1]. The theoretical model based on a self-consistently defined effective medium is found to better represent the experimental data points.

References:

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4:10 PM

Finite Element Modelling of Wave Propagation in Highly Scattering Materials
---**A. Van Pamel**, P. Huthwaite, C. Brett, and M. Lowe, Imperial College London, Mechanical Engineering Department, South Kensington Campus, London, SW7 2AZ, United Kingdom

---Polycrystalline materials are challenging for ultrasonic Non-destructive Evaluation (NDE). Unlike acoustically transparent media, the microstructure of some metals which we wish to inspect is sufficiently coarse such that it causes scattering of the propagating waves. A consequent increase in attenuation and coherent noise both hinder flaw detection, making inspection difficult. Until recently, the task of numerically modelling the wave scattering physics had been equally challenging. However, recent advances in computer technology have enabled step improvements, in particular the possibility of running realistically large Finite Element simulations. For this presentation, we have adopted this approach to simulate elastic wave propagation in both 2D and 3D, for a typical polycrystalline material favoured by the power industry. The scattering induced attenuation is compared with established theoretical predictions across a range of scattering regimes. The model is also used to provide useful insights into the ultrasonic array imaging of defects within these difficult materials.
---This work has been supported by the UK Research Centre in NDE, the Engineering and Physical Sciences Research Council grant EP/I017704/1, and E.ON Technologies (Ratcliffe) Ltd.

4:30 PM

Grain Scattering Measurements Using Cylindrically Focused Immersion Transducers at Normal Incidence

--Andrea Arguelles, Christopher M. Kube and Joseph A. Turner. Mechanical and Materials Engineering, University of Nebraska-Lincoln, W342 Nebraska Hall, Lincoln, NE, 68588, USA

--Grain scattering models often assume a single mode-type for the incident wave. Ultrasonic experiments to measure this grain scattering generally use spherically focused immersion transducers to generate the incident wave; these are assumed to generate purely longitudinal waves when placed at normal incidence with respect to the sample. However, the curvature of the transducer face when using focused probes results in some waves reaching the sample at oblique incidence and being mode-converted to shear vertical waves. In the case of spherically focused transducers, the displacement polarization of these shear waves is symmetric about the transducer center axis, as shown in Fig. 1(a). For cylindrically focused probes, the polarization of the shear waves is symmetric about the center plane, as seen in Fig. 1(b). This aspect of the measurement permits the transducer to be aligned at different orientations with respect to the sample in order to assess different microstructural traits. In other words, directionally dependent microstructural properties, such as elastic anisotropy and grain elongation can be evaluated by rotating the transducer about its axis relative to the sample. For this research, experimental backscatter measurements were performed on a rolled aluminum plate containing elongated grains using a cylindrically focused immersion transducer at normal incidence. The results indicate that the shear wave scattering contribution strongly depends on the direction and degree of grain elongation. Theoretical backscattering coefficients were derived to model the experimental configuration. This work has the potential to form a starting point for a simple NDE technique for microstructural characterization.

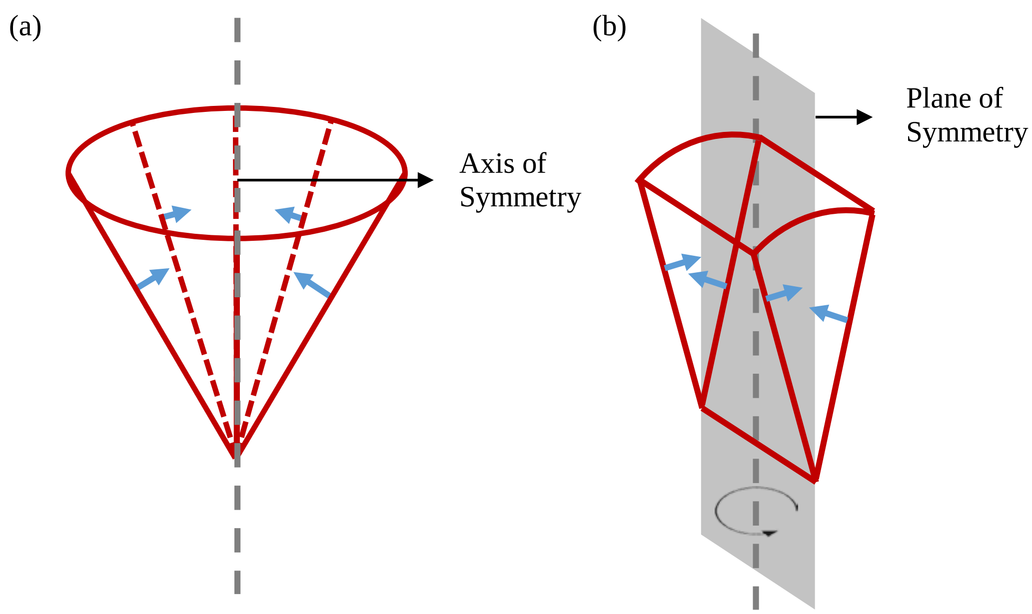

Figure 1. Displacement polarization direction (→) for shear wave generated when using (a) spherically focused and (b) cylindrically focused transducers.

4:50 PM

Mode-Converted Diffuse Ultrasonic Backscatter of Elongated Grains

---**Ping Hu**, Andrea Arguelles, Christopher M. Kube and Joseph A. Turner, University of Nebraska-Lincoln, Mechanical and Materials Engineering, W342 Nebraska Hall, Lincoln, NE 68588

---Elastic wave scattering in heterogeneous media can be measured using diffuse ultrasonic backscatter. Recently, a mode-converted diffuse ultrasonic backscatter model has been developed for evaluating the scattering response of a transverse wave from an incidence longitudinal wave in a polycrystalline medium with cubic, equiaxed, and single phase grains. In this presentation, the theoretical mode-converted scattering model is modified to include the case of grain elongation with in the sample. This model shows the dependence of scattering angle relative to the grain axis orientation. In addition, experimental measurements are discussed for a pitch-catch transducer configuration in a sample of 7475-T7351 aluminum alloy. The results show that the mode-converted scattering can be used to determine the dimensions of the elongated grains. Concurrently with these measurements, a pulse-echo transducer configuration measurement is also introduced to determine the corresponding material correlation lengths of grains, which are used to examine the shape effect of elongated grains on ultrasonic scattering. The average grain shape determined from the experimental measurements is compared with dimensions extracted from electron backscattered diffraction (EBSD), an electron imaging technique. The results suggest that mode-converted diffuse ultrasonic backscatter has the potential to quantify much detailed information about grain microstructure.

5:10 PM

Contribution of Double Scattering for Diffuse Ultrasonic Backscatter Measurements on Nickel Alloys

-- Ping Hu,[1] Nathanial Matz,[1] Sandra Dugan,[2] and **Joseph A. Turner**.[1], [1]Mechanical and Materials Engineering, University of Nebraska-Lincoln, W342 Nebraska Hall, Lincoln, NE, 68588, USA, [2]Abteilung ZfP im Anlagen- und Maschinenbau, Materialprüfungsanstalt Universität Stuttgart (MPA), Pfaffenwaldring 32, 70569 Stuttgart, Germany

--Nickel alloys are of high interest for many types of power plants including nuclear and next generation fossil fuel power plants that use high temperature steam, so called Advanced Ultrasupercritical (A-USC) power plants. Ultrasonic flaw detection in such alloys is influenced very strongly by grain scattering that can affect the quality of ultrasonic signals reflected from defects of interest. The grain noise can be modeled, in many cases, using a single-scattering assumption for which the incident energy is assumed to scatter once in the time between excitation and detection. Such a singly-scattered response (SSR) model is expected to break down when a strongly scattering material, like most nickel alloys, is examined. In these samples, it is expected that higher-order scattering effects are present but may not be easily identified as such. As a first step towards understanding this problem, a theory of the doubly-scattered response (DSR) was developed for illustrating the effects of double scattering. In this presentation, ultrasonic diffuse backscatter experimental measurements on two nickel alloys with different grain sizes are discussed for a pulse-echo transducer configuration. Experimental results from different frequencies and material focal depths are used to demonstrate the significance of these parameters on the scattered signal within a strongly scattering material. Average material correlation lengths can be extracted by combining the experimental measurements and the theoretical models for both SSR and DSR. These values are also compared with those determined from optical micrographs. The identification from experimental measurements on the theory of DSR demonstrates the breakdown of the SSR model for diffuse ultrasonic backscatter measurements in strongly scattering materials.

5:30 PM

Ultrasonic Scattering Measurements of Grain Size and Shape in Nickel and Titanium Alloys with Elongated Grains

--**Paul D. Panetta[1]**, Dale McElhone[1], Hualong Du[2], and Waled Hassan[3], [1]Applied Research Associates, Inc., 1206 Great Road Gloucester Point, VA 23062, [2]now at North Carolina State University Department of Mechanical and Aerospace Engineering 911 Oval Drive, Raleigh, NC 27695,[3] Rolls-Royce Corporation 546 South Meridian Street Indianapolis, IN 46225

The grain size of metal alloys is one of the key material properties that control mechanical strength. The grain size is carefully manipulated during processing to create the desired mechanical properties and reliability in a final component. Traditional metallographic grain size measurements are destructive, time consuming, and labor intensive. In addition they only sample a small region of a component and cannot be performed on every component. Ultrasonic scattering measurements are excellent at probing metal microstructures and providing a quantitative measurement of grain size if appropriate measurement methods and theories exist. In previous work we developed a software tool that unifies the entire process including the data collection, backscattering coefficient calculation, theoretical predictions, grain size calculation and visualization. We tested the backscattering measurement method on nickel super alloys including IN718, Waspaloy, Udimet 720, and Rene 88. Our results compared favorably with traditional metallography agreeing to within 2 microns for some nickel alloys.
We are now developing methods to characterize the elongated grains in the complex microstructures created by additive manufactured methods as well as titanium alloys.

---This work funded by the FAA William J. Hughes Technical Center under Contract# DTFACT-13- C-00027

Session 35

SESSION 35
BENCHMARKS
Paul Schafbuch, Chairperson
Nicollet D3

3:30 PM **Results of the 2015 UT Modeling Benchmark Obtained with Models Implemented in CIVA**
---Gwénaël Toullelan[1], Raphaële Raillon[1], Sylvain Chatillon[1], Vincent Dorval[1], and Sébastien Lonne[2], [1]CEA, LIST, 91191 Gif-sur-Yvette, France; [2]EXTENDE, Le Bergson, 15 Avenue Emile Baudot, 91300 Massy, France

3:50 PM **Solution of the WFNDEC 2015 Eddy Current Benchmark with Modal and Numerical Methods**
---**Roberto Miorelli**, Anastasios Skarlatos, and Christophe Reboud, CEA, LIST, Département Imagerie et Simulation pour le Contrôle, Gif-sur-Yvette 91191, France; Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani 50100, Greece; Nikolaos Poulakis, Technological Education Institute of Western Macedonia, Department of Electrical Engineering, Koila 50100, Greece

4:10 PM **2015 WFNDEC Eddy Current Benchmark Modeling of Impedance Variation in Coil Due to a Crack Located at the Plate Edge**
---**João V. G. Rocha**, Cesar G. Camerini, and Gabriela R. Pereira, Laboratory of Non-Destructive Testing, Corrosion and Welding, Federal University of Rio de Janeiro – RJ, Brazil

3:30 PM

Results of the 2015 UT Modeling Benchmark Obtained with Models Implemented in CIVA

---**Gwénaël Toullelan**[1], Raphaële Raillon[1], Sylvain Chatillon[1], Vincent Dorval[1], and Sébastien Lonne[2], [1] CEA LIST, 91191 Gif-sur-Yvette, France; [2] EXTENDE, Le Bergson, 15 Avenue Emile Baudot, 91300 Massy, France

---For several years, the World Federation of NDE Centers, WFNDEC, proposes benchmark studies in which simulated results (in either ultrasonic, X-rays or eddy current NDT configurations) obtained with various models are compared to experiments. On previous years UT benchmarks have mostly addressed pulse echo mode. This year the proposed benchmark concerns TOFD technique. TOFD is today commonly used for locating and sizing cracks from tip diffraction echoes. This technique relies on an arrangement of two probes with opposite beam directions. Experiments have been carried out on a planar block containing one vertical planar surface breaking flaw of 15mm height. L45°, L60° and L70° acquisitions of top and bottom tip diffraction echoes have been performed with various PCSs (Probe Center Spacing), the PCS being an important parameter for the TOFD inspection performances. This communication presents the results obtained for this benchmark with the models implemented in the CIVA software. To calculate the diffraction echoes, the field radiated by the probe is first computed on the notch edges by applying the pencil-model and used, in a second time, as an input for the beam/defect interaction model used to predict the responses from the notch edges: the GTD model (Geometrical Theory of Diffraction). In the previous release of CIVA, the so called "plane wave approximation" was applied to exploit the elastodynamics field: it was described by a time of flight, a complex amplitude, a direction of propagation and a direction of polarization were extracted. Now, the whole description of the elastodynamics field can be used as an input of the defect response model. The comparison between experimental and simulated results obtained with these field descriptions are presented and discussed.

3:50 PM

Solution of the WFNDEC 2015 Eddy Current Benchmark with Modal and Numerical Methods

---**Roberto Miorelli,** Anastasios Skarlatos, and Christophe Reboud, CEA, LIST, Département Imagerie et Simulation pour le Contrôle, Gif-sur-Yvette 91191, France; Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani 50100, Greece; Nikolaos Poulakis, Technological Educational Institute of Western Macedonia, Department of Electrical Engineering, Koila 50100, Greece

---The 2015 eddy current benchmark, proposed by the World Federation of NDE Centers [1], deals with the modeling of the edge effects when inspecting a planar piece in view of flaw detection. Such geometrical effects perturb in general much more the eddy current density generated by the probe than the crack itself, so they logically yield signals with much greater amplitude. The configuration addressed here is voluntarily simple in terms of piece geometry and sensor used, so that experimental conditions are well handled and the acquisition noise is negligible. Measured data are recorded using an impedance meter –that is, they comparable to simulation results without need of any calibration process.
This communication presents two solutions for simulating this benchmark, which are both based on an integral equations formalism, in which the narrow cracks are described as unknown fictitious sources [2]. However, they use very different theoretical bases for the computation of induced field and interaction operators. In the first method, a fast modal description of electric fields, well-suited to the canonical setup of this benchmark, is introduced. In the second one, the same quantities are obtained with a mixed numerical/modal formulation [3] involving the Finite Integration Technique (FIT), which can handle more complex piece geometries. Results obtained with both methods are presented and discussed in the full paper.

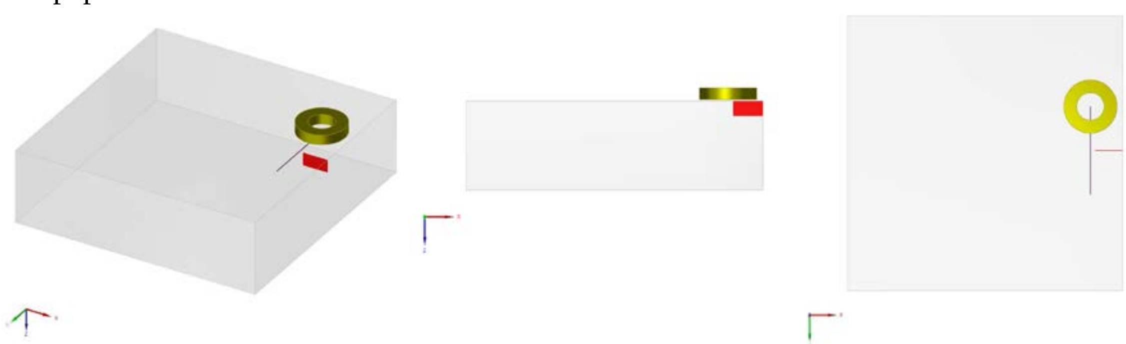

Figure 1. Schematic views of the benchmark case.

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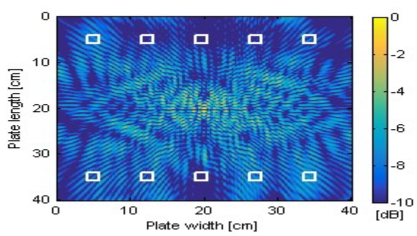
2. Bowler, J.R.; Theodoulidis, T.P.; Poulakis, N., "Eddy Current Probe Signals Due to a Crack at a Right-Angled Corner", IEEE Transactions on Magnetics, vol. 48 (12), pp 4735-4746 (2012), http://dx.doi.org/10.1109/TMAG.2012.2203918
3. Skarlatos, A. and Reboud, C., "Eddy-current inspection modelling of symmetrical work-pieces using three-dimensional probes based on a mixed numerical/modal formulation", AIP Conference Proceedings, 1581, 1413-1420 (2014), http://dx.doi.org/10.1063/1.4864987

4:10 PM

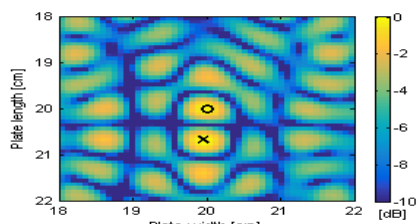
Multidimensional Guided Wave Dispersion Recovery for Locating Defects in Composite Materials

---**Joel B. Harley**[1] and Luca De Marchi[2], [1]Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT 84112; [2]Department of Electronics, Computer Sciences and Systems (DEIS), University of Bologna, Bologna, Italy

---In recent years, the use of fiber reinforced composites in newly manufactured aerospace and civil structures has grown at a rapid rate. Compared with traditional metals, composites offer the advantage of greater strength, greater flexibility, and lighter weight. Yet, ensuring the structural health and integrity of composite structures is a significant challenge. Defects in composite materials are difficult to detect by visual inspection and with traditional nondestructive testing methods. Ultrasonic guided waves have shown significant promise for detecting composite defects. Yet for composites materials, guided wave methods are often limited by complex and unknown wave propagation characteristics. Wave propagation characteristics vary as a function of propagation direction and these characteristics vary significantly with the manufacturing process. As a result, there is a significant need for methods that can estimate the direction-dependent characteristics of a composite structure and use these estimates to detect and locate defects. In this paper, we address this need by adapting prior work on sparse wavenumber analysis [1] and data-driven matched field processing [2]. We use sparse wavenumber analysis to recover the multidimensional dispersion curves of a composite plate. We then integrate the multidimensional dispersion curves with data-driven matched field processing to locate the defect. We experimentally demonstrate this approach by utilizing guided wave measurements from a scanning laser doppler vibrometer to locate an acoustic source in the center of a unidirectional, fiberglass composite plate. Figure 1(a) illustrates the resulting image across the plate and Figure 1(b) illustrates the image near the source location. The white squares denote 10 measurement locations, the black circle denotes the true location of the source, and the black cross represents the estimated location the source (i.e., the image's maximum value). The distance error is 0.6726 cm. These results illustrate that we can achieve high localization accuracy with relatively few sensors. In the paper, we further describe how our method is implemented and then compare it with other guided wave approaches.



(a)



(b)

Figure 1. Localization results (a) across the entire plate and (b) around the acoustic source on a undirectional fiberglass plate. The white squares represent locations of each measurements used, the black circle represents the true source location, and the black cross represents the estimated location.

References:

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FRIDAY

FRIDAY, JULY 31, 2015

	Session 36 Non-Contact and Laser Ultrasonics *Nicollet D1*	Session 37 Characterization *Nicollet D2*	Session 38 Eddy Current II *Nicollet D3*	Session 39 Structural Health Monitoring *Lakeshore A*
8:30 AM				
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Session 36

SESSION 36
NON-CONTACT AND LASER ULTRASONICS
Jean Pierre Monchalin and Daniel Levesque, Co-Chairpersons
Nicollet D1

8:30 AM **Focusing of Ferroelectret Air-Coupled Ultrasound Transducers**
---**Mate Gaal**, Jürgen Bartusch, Elmar Dohse, and Enrico Köppe, Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

8:50 AM **Rapid Non-Contact Inspection of Composite Ailerons Using Air-Coupled Ultrasound**
---**Rabi Sankar Panda**[1], Krishnan Balasubramaniam[1], Prabhu Rajagopal[1], Oleksii Karpenko[2], Lalita Udpa[2] and Mahmoodul Haq[3], [1]Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, Tamil Nadu, India; [2]Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824; [3]Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824

9:10 AM **Non-Contact Ultrasonic Defect Imaging in Composites**
---**Frédéric Cohen Tenoudji**[1,2], Jean Marie Citerne[1,2], Hugo Dutilleul[1,2], and Dominique Busquet[1,2], [1]Sorbonne Universités, UPMC Univ Paris 06, UMR 7190, Institut Jean le Rond d'Alembert, F-75005, Paris, France; [2]CNRS, UMR 7190, Institut Jean le Rond d'Alembert, F-75005, Paris, France

9:30 AM **Influence of the Superficial Layer on the Directivity Patterns of Ultrasonic Waves Generated by Laser in a Bi-Layer Sample**
---**E. Anagnostopoulos**[1], D. Ségur[1], T. Dehoux[2], and B. Audoin[3], [1]CEA, LIST, Département Imagerie Simulation pour le Contrôle, France; [2]CNRS, 12M, UMR 5295, F-33400 Talence, France; [3]Univ. Bordeaux, 12M, UMR 5295, F-33400 Talence, France

9:50 AM **Spatially Resolved Acoustic Spectroscopy (SRAS) Recent Developments and Progress Towards an Industrial Prototype**
---**Jethro Coulson[1,2]**, Wenqi Li[1], Richard Smith[1], and Steve D. Sharples[1], [1]Applied Optics Group, University of Nottingham; [2]Renishaw plc.

10:10 AM ***Break***

10:30 AM **Elastic Limit in Laser Shockwave Experiments to Relate Velocity Measurements**
---**James A Smith** and Jeffrey M. Lacy, Idaho National Laboratory, Idaho Falls, ID 83415; Daniel Lévesque, Jean-Pierre Monchalin, and Martin Lord, National Research Council Canada, Boucherville, QC, Canada

10:50 AM ***Adjourn***

8:30 AM

Focusing of Ferroelectret Air-Coupled Ultrasound Transducers

---**Mate Gaal**, Jürgen Bartusch, Elmar Dohse, and Enrico Köppe, Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

---Air-coupled ultrasound has been applied increasingly as a non-destructive testing method for lightweight construction in recent years. It is particularly appropriate for composite materials being used in automotive and aviation industry [1]. Air-coupled ultrasound transducers mostly consist of piezoelectric materials and matching layers. However, their fabrication is challenging and their signal-to-noise ratio often not sufficient for many testing requirements. To enhance the efficiency, air-coupled ultrasound transducers made of cellular polypropylene have been developed [2]. Because of its small density and sound velocity, this piezoelectric ferroelectret matches the small acoustic impedance of air much better than the matching layers applied in conventional transducers. In our contribution, we present two different methods of spherical focusing of ferroelecret transducers for the further enhancement of their performance in NDT applications. An example of a focused ferroelectret transducer is shown in Fig. 1. Measurements on carbon-fiber-reinforced polymer (CFRP) samples and on metal adhesive joints performed with commercially available focused air-coupled ultrasound transducers will be compared to measurements executed with self-developed focused ferroelectret transducers.---
The work is funded by the ZIM program of the Federal Ministry for Economic Affairs and Energy, Germany.

Figure 1. Example of a focused ferroelectret transducer.

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8:50 AM

Rapid Non-Contact Inspection of Composite Ailerons Using Air-Coupled Ultrasound

---Rabi Sankar Panda[1], Krishnan Balasubramaniam[1], Prabhu Rajagopal[1], Oleksii Karpenko[2], Lalita Udpa[2] and Mahmoodul Haq[3], [1]Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, Tamil Nadu, India; [2]Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824; [3]Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824

---This paper demonstrates an approach for rapid non-contact air-coupled ultrasonic inspection of composite ailerons with complex cross-sectional profile including thickness changes, curvature and the presence of a number of stiffeners. Low-frequency plate guided ultrasonic modes are used in B-scan mode for the measurements in pitch-catch mode. Appropriate probe holder angles suitable for generating and receiving lower order guided wave modes are discussed. Different embodiments of the pitch-catch tandem positions along and across stiffener and curved regions of the test sample enable a rapid test campaign capturing the feature-rich sample profile. Techniques to distinguish special features in the stiffener are presented. Additionally, finite element (FE) models are created and validated with experimental data to visualize guided wave propagation and its interaction with defects in these critical structural components.

9:10 AM

Non-Contact Ultrasonic Defect Imaging in Composites

---**Frédéric Cohen Tenoudji**[1,2], Jean Marie Citerne[1,2], Hugo Dutilleul[1,2], and Dominique Busquet[1,2], [1]Sorbonne Universités, UPMC Univ Paris 06, UMR 7190, Institut Jean le Rond d'Alembert, F-75005, Paris, France; [2]CNRS, UMR 7190, Institut Jean le Rond d'Alembert, F-75005, Paris, France

---In the situations where conventional NDT ultrasonic techniques using immersion of the part under inspection or its contact with the transducers cannot be used, in-air investigation presents an alternative. The huge impedance mismatch between the part material and air (transmission loss in the order of 80 dB for a thin metallic plate) induces having to deal very small signals and unfavorable signal to noise ratios. The approach adopted here is the use of the crack of a spark generated by induction as a sound source and an electrostatic polyethylene membrane microphone as a receiver [1]. The advantage of this source is that the spark power is high (several kilowatts) and its power is directly coupled to air during the energy release. In some difficult situations, an elliptical mirror is used to concentrate the sound beam power on the surface of the part. The stability and reproducibility of the sound generated by the spark which is a necessity in order to perform quantitative evaluations is achieved in our experiment. It permits also an increase of the signal to noise ration by signal accumulation. The sound pulse duration of few microseconds allows operating in pulse echo in some circumstances. The bandwidth of the source is large, of several hundred of kilohertz, and that of the microphone of about 100 kHz allow the flexibility to address different kinds of materials. The technique allows an easy, in-air, non contact, inspection of structural composite parts, with pulse waves, with an excellent signal to noise ratio. An XY ultrasonic scanning ultrasonic system for material inspection using this technique has been realized. Results obtained in transmission and reflection are presented. Defects in carbon composite plates and in honeycomb are imaged in transmission (Fig.1). Echographic measurements show that defect detection can be performed in thin plates using Lamb waves propagation when only one sided inspection of the part is possible. The scanner resolution and precision of measurements are discussed.

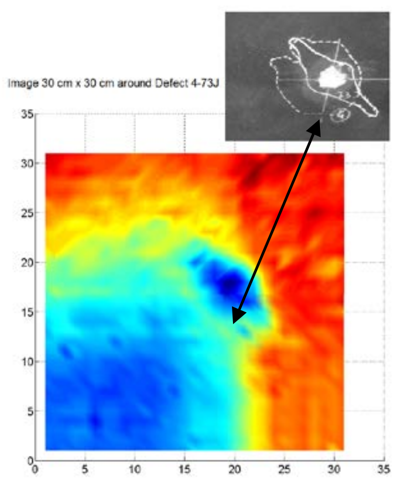

Figure 1. US image and photo of a defect in a honeycomb plate.

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9:30 AM

Influence of the Superficial Layer on the Directivity Patterns of Ultrasonic Waves Generated by Laser in a Bi-Layer Sample

---**E. Anagnostopoulos**[1], D. Ségur[1], T. Dehoux[2], and B. Audoin[3], [1]CEA, LIST, Département Imagerie Simulation pour le Contrôle, France; [2]CNRS, I2M, UMR 5295, F-33400 Talence, France; [3]Univ. Bordeaux, I2M, UMR 5295, F-33400 Talence, France

---Many previous experimental studies have shown that the presence of a superficial layer over a substrate plays an important role in the amplitude of the ultrasonic wave generated by a pulsed laser. Today in the field of non-destructive testing using the Laser Ultrasonics Technique (LUT), it is common to spray a highly absorbing paint layer on the surface of the inspected part to improve the ultrasonic generation. In aerospace industry, LUT provides an effective technique to test large composite panels. However, in order to reduce the time and cost of composite manufacturing, the paint coating has to be removed from the process. As a consequence, the laser ultrasonics generation mechanism has to be well understood in bare composite structures. In such parts, the laser is absorbed directly by the composite itself, and new features in the laser ultrasonics generation mechanism arise from the presence of the superficial resin layer. This layer has a variable thickness, typically comprised between 20µm and 150µm. Depending on the optical wavelength of the generation laser, the resin layer can be considered as totally transparent and therefore the acoustic source is located at the resin/composite interface, or it can be semi- transparent and thus it absorbs partially the electromagnetic energy. In the latter case, the acoustic source is distributed within the layer volume and contributes to the total radiated acoustic field. The aim of this work is to study the acoustic generation in a layer/substrate geometry in both mentioned generation situations. The presented work is a simplified approach of the generation in composite materials as we consider both the skin layer and the substrate as isotropic materials. A two dimensional analytical model for the calculation of the directivity patterns based on the reciprocity theorem has been developed. The superficial layer can be considered as transparent or absorbing, according to the laser wavelength while the substrate is regarded as opaque. All the main parameters of the thermoelastic laser generation, such as the layer thickness, the pulse duration, the laser spot radius and the optical penetration depth into the superficial layer are taken into account. We demonstrate here that enhancement of the acoustic waves along privileged directions can be achieved for precise acoustic wavelength to layer thickness ratios. For a layer of zero thickness we obtain the typical directivity patterns of a thermoelastic acoustic source localized at the surface of an isotropic half-space. For a small layer thickness compared to the acoustic wavelength the resulting directivities are mostly enhanced in the normal direction. For a large layer thickness compared to the acoustic wavelength a situation combining the two previous cases is obtained. Finally we discuss the effect of the acoustic impedance ratio between the layer and the substrate.

9:50 AM

Spatially Resolved Acoustic Spectroscopy (SRAS) Recent Developments and Progress towards an Industrial Prototype

---**Jethro Coulson**[1,2], Wenqi Li[1], Richard Smith[1], and Steve D Sharples[1], [1]Applied Optics Group, University of Nottingham; [2]Renishaw plc.

---Spatially Resolved Acoustic Spectroscopy (SRAS) is a non-contact laser ultrasonic technique which allows the rapid determination of surface microstructure through highly localised measurements of surface acoustic wave (SAW) phase velocities [1]. SRAS can resolve grain structure down to ~30 µm and collects data at a rate of ~2000 points per second. By taking multiple SRAS scans at equally spaced SAW propagation directions, a velocity surface for each scanned point can be measured. These can be compared against a database of modelled velocity surfaces for a given material, obtaining full crystallographic orientation [2]. Current techniques to determine microstructure suffer various drawbacks: sample preparation and maximum size for EBSD, qualitative data only for etching and microscopy, and limited resolution for X-Ray techniques. As such SRAS has been developed from a lab based demonstrator into an industrial prototype in collaboration with Renishaw. The new instrument allows scanning of complex 3D surfaces over sample sized up to 700mm in diameter.---This work is funded by EPSRC with contributions from the Royal Commission for the Exhibition of 1851

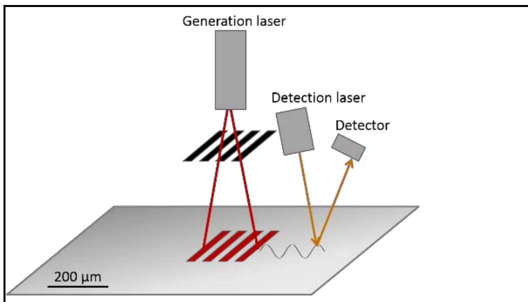

Figure 1: A schematic of the SRAS system.

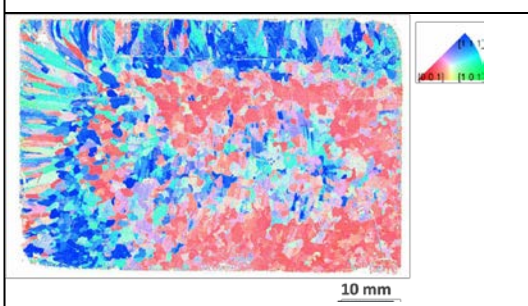

Figure 2: An inverse pole figure of a large grained aluminium sample captured using SRAS.

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10:30 AM

Elastic Limit in Laser Shockwave Experiments to Relate Velocity Measurements

---James A. Smith and Jeffrey M. Lacy, Idaho National Laboratory, Idaho Falls, ID 83415; Daniel Lévesque, Jean-Pierre Monchalin, and Martin Lord, National Research Council Canada, Boucherville, QC, Canada

---The Idaho National Laboratory (INL) has been developing a Laser Shock system to characterize interface strength in plate fuel for research reactors around the world [1]. This work is in support of the Unites states High Performance Research Reactor program whose goal is to reduce the risk of proliferation of weapons grade fuel while maintaining reactor performance. The INL has been working with National Research Council Canada (NRC) on this project for the last five years. One of the concerns of the project is the difficulty of calibrating and standardizing the laser shock technique. The generation of the stress wave by the laser impinging on the plate surface is complex, with amplitude and shape dependence on numerous factors relating to the temporal and spatial distribution of power in the laser spot, surface treatment, and material properties of the plate. Thus the resulting back-face surface velocity, which is used to measure the time-varying stress field within the plate, is difficult to reproduce across different measurement systems. A technique that can generate or indicate a known shock intensity independent of the generating conditions would be valuable and allow us to directly compare results from different systems. A Laser Shock round robin test between the system at NRC and the INL was conducted. The goal of the round robin was to determine if there was any bias between the two systems. During the analysis of the data, it was noted that the Hugoniot Elastic Limit (HEL) was consistent within both system data sets independent of the laser power used. An analytical study under development supports that the HEL in metals could be a robust and simple benchmark to compare stresses generated by different laser shock systems. The HEL is a material property that should be insensitive to differences in the shock laser and surface preparation which enhances the reliability of the resulting HEL velocity measurement.

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1. J. M. Lacy, J. A. Smith and B. H. Rabin, "Developing a Laser Shockwave Model for Characterizing Diffusion Bonded Interfaces," The 41st Annual Review of Progress in Quantitative Nondestructive Evaluation," Boise, ID, U.S.A., July 2014.

Session 37

SESSION 37
CHARACTERIZATION
R. A. Adebisi and Marc Keutzbruck, Chairpersons
Nicollet D2

8:30 AM **Characterization of Cohesive and Adhesive Properties of Adhesive Bonds Using Transmitted Ultrasonic Waves**
---Emmanuel Siryabe[1], **Mathieu Renier**[1], Anissa Meziane[1], Jocelyne Galy[2], and Michel Castaings[1]; [1]Univ. Bordeaux, I2M, UMR 5295 CNRS, Bordeaux INP, Arts et Métiers Paris Tech, F-33400, Talence, France; [2]Laboratoire Ingénierie des Matériaux Polymères, IMP – UMR 5223 CNRS- INSA Lyon, Villeurbanne Cedex, France

8:50 AM **Crack Growth Monitoring at CFRP Bond Lines**
---**Markus Rahammer**, Wolfgang Adebahr, Stefan Gröninger, and Marc Kreutzbruck, University of Stuttgart, Institut für Kunststofftechnik, 70569 Stuttgart, Germany; Ronny Sachse, University of Stuttgart, Institute of Aircraft Design, 70569 Stuttgart, Germany

9:10 AM **Modern Non-Destructive Testing and Characterization Methods for the Inspection of Composite Materials and Components**
---**Marc Kreutzbruck**, University of Stuttgart, Institut für Kunststofftechnik, 70569 Stuttgart, Germany

9:30 AM **Evaluation of Grain Size in Curved Component Using an Ultrasonic Attenuation Method with Diffraction Correction**
---Chenxin Zhang[1], Xiongbing Li[1,2], and Xiaoqin Han[1], [1]CAD/CAM Institute, Central South University, Changsha, Hunan 410075, China; [2]State Key Laboratory of Powder Metallurgy, Central South University, Changsha, Hunan 410083, China

9:50 AM **Stress Measurement by Evaluation of Thermal Conductivity**
---Libing Bai, Yuhua Cheng, Xiaodong Zhou, Chun Yin, Kai Chen, and Jie Zhang, University of Electronic Science and Technology of China, School of Automation Engineering, Chengdu, 611731, China

10:10 AM **Break**

10:30 AM **Magnetic Hysteresis Model Considering Microstructural Feature Distribution**
---Jun Liu and Claire Davis, University of Warwick, Warwick Manufacturing Group, Coventry CV4 7AL, United Kingdom

10:50 AM **Experimental Study of Ultrasonic Lamb Wave Mixing During Tempering of Modified 9Cr-1Mo Steel**
---Avijit Kr Metya[1,2], M. Ghosh[1], N. Parida[1], and Krishnan Balasubramaniam[2], [1]MST Division, CSIR-National Metallurgical Laboratory, Jamshedpur-831007, India; [2]Center for NDE, Mechanical Engineering Department, IIT-Madras, Chennai-600036, India

11:10 AM **Elastic Constants Measurements of a Ti–7al Using Resonant Ultrasound Spectroscopy**
---R. A. Adebisi[2], S. Sathish[2], and P. A. Shade[1], [1]Air Force Research Laboratory, Wright Patterson AFB OH 45433; [2]University of Dayton Research Institute, Dayton OH, 45469

11:30 AM ***Adjourn***

8:30 AM

Characterization of Cohesive and Adhesive Properties of Adhesive Bonds Using Transmitted Ultrasonic Waves

---Emmanuel Siryabe[1], **Mathieu Renier**[1], Anissa Meziane[1], Jocelyne Galy[2], and Michel Castaings[1]; [1]Univ. Bordeaux, I2M, UMR 5295 CNRS, Bordeaux INP, Arts et Métiers Paris Tech, F-33400, Talence, France; [2]Laboratoire Ingénierie des Matériaux Polymères, IMP – UMR 5223 CNRS- INSA Lyon, Villeurbanne Cedex, France

---The increasing production of adhesively bonded joints requires non-destructive evaluation methods to be developed for safety reasons. An adhesive joint can be divided into two sensitive zones that may cause mechanical failure: the body of the adhesive (cohesive zone) and the adhesive-substrate interphase (adhesion zone). "Cohesive" defects can come for example from an imperfect curing of the adhesive. "Adhesives" defects can result from inappropriate surface treatment of the substrate. The present research attempts to characterize mechanical properties, which are representative of the adhesive and cohesive states of adhesively bonded assemblies, using an ultrasonic method. To simplify the approach, the assemblies are made of two aluminum substrates and an epoxy-based adhesive layer. The elastic *moduli* of these materials have been previously measured on individual components (one aluminum plate and two epoxy plates with 80% or 100% of full curing). Six bonded samples were manufactured: three for which the adhesive is fully cured (100%) and three for which crosslinking is partial (80%). For each level of curing, three different surface treatments were applied to the aluminum substrates before assembling, in order to vary the quality of adhesion: (1) degreasing, sandblasting and Silane treatment (reference sample with nominal adhesion properties), (2) degreasing and sandblasting (intermediate expected adhesion) and (3) degreasing only (weak adhesion). Transmission coefficients of an ultrasonic plane wave incident from different angles are then measured for each sample immersed in a water tank. Knowing the thicknesses and mass densities of the components, as well as the elastic *moduli* of the aluminum (previously measured), the stiffness layer method serves as a support for solving an inverse problem, which provides the desired adhesive and cohesive properties. Firstly, for the reference samples, three layers are considered in the model and perfect continuity of displacements and stresses at the aluminum-epoxy interfaces. The epoxy *moduli* are then optimized and match very well the values measured on the individual epoxy samples (fully or partially cured). Then, two thin layers (h = 1 μm) are added in the model to simulate the interphases; their mechanical characteristics (C_{11}, C_{66} or $C_{11}=K_L/h$, $K_T=C_{66}/h$) are optimized in turn to assess their values when adhesive properties are *a priori* nominal. Then, the same process is applied to samples with intermediate and weak levels of adhesion. If only three layers are considered, i.e. if perfect adhesion is assumed, the evaluation of the epoxy *moduli* reveals a strong apparent anisotropy. This abnormal result is an indicator of the degraded interphases; this interesting result has been confirmed by fully numerical investigations. Finally, assuming that the epoxy *moduli* remained unchanged (same values as individual or reference assemblies, but depending on the level of curing) the optimization of the characteristics of these interphases lead to much lower values of the interface stiffnesses, $K_L=C_{11}/h$ and $K_T=C_{66}/h$. These results show the strong potential of the method to distinguish between adhesive and cohesive weaknesses of bonded joints, and to quantify corresponding mechanical properties (elastic *moduli* or interfacial stiffnesses).

8:50 AM

Crack Growth Monitoring at CFRP Bond Lines

---**Markus Rahammer**, Wolfgang Adebahr, Stefan Gröninger, and Marc Kreutzbruck, University of Stuttgart, Institut für, Kunststofftechnik, 70569 Stuttgart, Germany; Ronny Sachse, University of Stuttgart, Institute of Aircraft Design, 70569 Stuttgart, Germany

---With the growing need for lightweight technologies in aerospace and automotive industries, fibre-reinforced plastics, especially carbon-fibre (CFRP), are used more and more. A promising joining technique for composites is adhesive bonding. While rivet holes destroy the fibres and cause stress concentration, adhesive bond lines distribute the load evenly. Today bonding is only used in secondary structures due to a lack of knowledge in long-term predictability. As in all industries, numerical simulation plays a critical part in the development process of new materials and structures. Numerical modelling of adhesive bondings conduces to the predictability of life time and damage tolerance. The critical issue with adhesive bondings is crack growth. In a dynamic tensile stress testing machine we dynamically load bonded CFRP coupon specimen and measure the growth rate of an artificially started crack in order to feed the models with the results. We also investigate the effect of mechanical crack stopping features. For observation of the bond line, we apply two non-contact NDT techniques: Air-coupled ultrasound in slanted transmission mode and active lockin-thermography evaluated at load frequencies. Both methods give promising results for detecting the current crack front location. While the ultrasonic technique provides a slightly higher accuracy, thermography has the advantage of true online monitoring, because the measurements are made while the cyclic load is being applied. The NDT methods are compared to visual inspection of the crack front at the specimen flanks and show high congruence. Furthermore, the effect of crack stopping features within the specimen on the crack growth is investigated. The results show, that not all crack fronts are perfectly horizontal, but all of them eventually come to a halt in the crack stopping feature vicinity.---Two of the authors (M.R. and R.S.) acknowledge support of this study in the framework of BOPACS project funded from the European Union's Seventh Framework Program for research, technological development and demonstration under grant agreement No. ACP2-GA-2012- 314180-BOPACS.

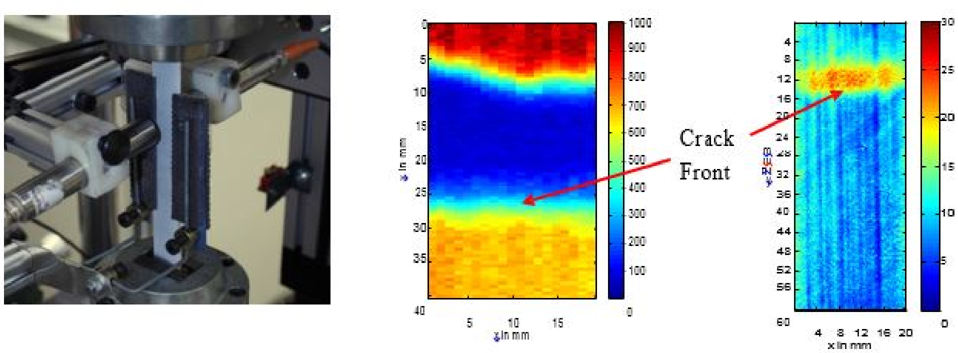


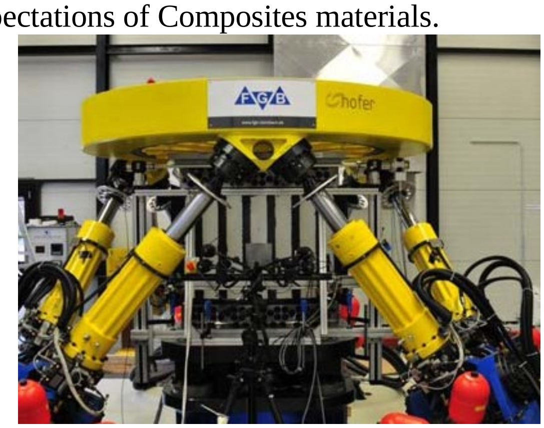
Figure 1. Non-destructive testing of a CFRP bond line. Photograph of the test setup (left), ultrasonic C-Scan (middle), Lockin-Thermography phase image (right).

9:10 AM

Modern Non-Destructive Testing and Characterization Methods for the Inspection of Composite Materials and Components

---**Marc Kreutzbruck**, University of Stuttgart, Institut für Kunststofftechnik, 70569 Stuttgart, Germany

---Aviation and Automotive dominate the global trend to use modern lightweight components. Especially fiber-reinforced plastic composites (FRP) have great potential for making the vehicles of the future even more lightweight and economical. It is important to start thinking now about the non-destructive testing (NDT) of the fiber composite parts of tomorrow with the aim of providing reliable, fast and inexpensive evidence of typical material defects before and during service. The talk illuminates modern NDT-techniques such as thermal, electromagnetic and acoustical inspection methods. This includes ultrasonic testing procedures using air coupled ultrasonic testing guided waves or even the use of sophisticated matrix arrays in contact techniques. The latter helps to provide a tomographic-like 3D-image of damage in CFRP samples thus increasing the contrast and the lateral resolution for more reliable defect recognition and interpretation. In addition we also show alternative approaches such as Local Defect Resonance (LDR), in which we exploit the change of mechanical properties in the vicinity of material defects. Resonance behavior can be imaged by detecting heat, surface movement or vibrations. Besides the overview of new CFRP-adapted NDT methods we also show that NDT techniques can be used for condition monitoring and life time expectations of Composites materials.



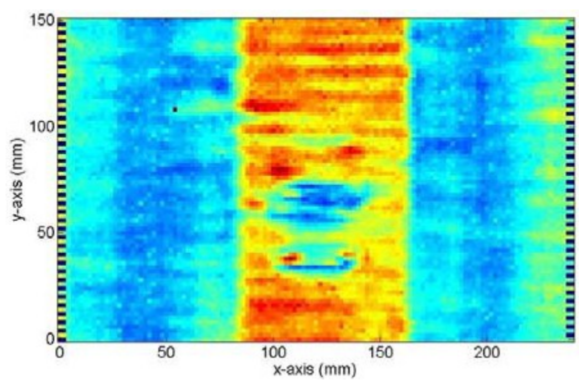


Figure 1. Left: Cycle fatigue testing of large aircraft CFRP components using multi axial hexapod technology [1]. Right: Results of in-situ NDT with single side access. Guided waves C-scan generated by air-coupled transducers to monitor the crack growth.

References:

1. The investigations in Figure 1 were performed in cooperation with the Institute of Polymer & Composites at the Technical University of Hamburg (Prof. B. Fiedler), The University of Braunschweig (Prof. P. Horst), and the Technical University of Dresden (Prof. M. Gude)

9:30 AM

Evaluation of Grain Size in Curved Component Using an Ultrasonic Attenuation Method with Diffraction Correction

---**Chenxin Zhang**[1], Xiongbing Li[1,2], and Xiaoqin Han[1], [1]CAD/CAM Institute, Central South University, Changsha, Hunan 410075, China; [2] State Key Laboratory of Powder Metallurgy, Central South University, Changsha, Hunan 410083, China

---Ultrasonic attenuation method has been investigated as an effective tool of the grain size nondestructive evaluation. The ultrasonic diffraction caused by the curved surface will bring in systematic error and thus inaccurate the evaluation. The multi-Gaussian beam simulation for ultrasonic wave propagation in curved component is presented. Thereafter, it is combined with the system function to deduce the ideal transmission model without scattering. AISI 304 stainless steel blocks with different grain sizes and curvature are used in attenuation measuring experiment. On the basis of the experimental results and the ideal transmission model, an ultrasonic attenuation model with diffraction correction is established. Using FFT method to draw the frequency spectrum of ultrasonic attenuation for each block, which aims to obtain the interrelationship of the grain size, curvature and the attenuation. Compared with the traditional attenuation method, the proposed method can reduce systematic error caused by ultrasonic diffraction and improve the applicability and reliability of grain size evaluation. Numerical and analytical calculation for the curved block with the radius of 30mm and the grain size of 72.35 μm are conducted. The results show the systematic errors of traditional attenuation method and the proposed model are 17.55% and 5.49%, respectively.---This work was supported by the National Natural Science Foundation of China (Grant nos. 61271356), Natural Science Foundation Hunan Province (Grant no. 14JJ2002), and China Postdoctoral Science Foundation funded project (Grant no. 2014M562126).

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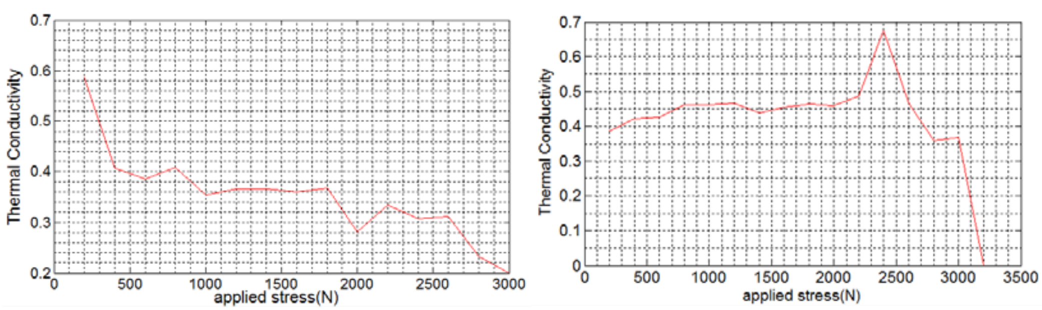
9:50 AM

Stress Measurement by Evaluation of Thermal Conductivity

---Libing Bai, Yuhua Cheng, Xiaodong Zhou, Chun Yin, Kai Chen, and Jie Zhang, University of Electronic Science and Technology of China, School of Automation Engineering, Chengdu, 611731, China

---Material stress can affect the internal structure of the lattice, which leads to change of electrical conductivity and thermal conductivity [1]. Eddy current pulsed thermography contains two parts: eddy current excitation and thermal conduction. The process of eddy current excitation has been deeply investigated in our previous paper, which presents the relationship between electrical conductivity and uniaxial tensile stress [2]. Compared with the first part, thermal conduction process lasts longer which conceives more information of material. Therefore, a new method is proposed to characterize the stress through thermal conductivity variation. In this method, heat flux and temperature gradient is firstly measured. And then, thermal diffusion coefficient is calculated through heat conduction differential equations. The test results show that the thermal conductivity of steel becomes anisotropic under uniaxial tensile stress. In the other word, when stress increases, thermal conductivity decreases in the perpendicular direction of stress, and increases in the parallel direction, as shown in Fig.1. Therefore, eddy current pulsed thermography can evaluate electrical conductivity variation along eddy current direction [2], and thermal conductivity along eddy current perpendicular direction in a single measurement. This complementarity promises the potential of residual stress mapping.



(a) Perpendicular to the applied stress (b) Parallel to the applied stress

Figure 1. The relationship between thermal conductivity and applied stress.

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10:30 AM

Magnetic Hysteresis Model Considering Microstructural Feature Distribution

---**Jun Liu** and Claire Davis, University of Warwick, Warwick Manufacturing Group, Coventry CV4 7AL, United Kingdom

---Non-destructive characterization of steel microstructure using electromagnetic (EM) sensors can be used for process control during fabrication or damage monitoring in-service since microstructural features, such as grain size, phase balance, precipitation etc, affect the magnetic response. It is desirable to be able to model the effects of these features on the magnetic BH curve such that measurement of the appropriate parameters, showing greatest sensitivity to the features of interest, can be proposed for any given engineering application. Major/minor loop measurements have the potential of being used to look at selected microstructural features of interest, for example through minor loop measurement with different bias fields. The major challenge is to correlate the measured major/minor loop parameters and/or magnetic properties with the microstructural features of interest so that, ultimately, it is possible to inversely evaluate the microstructural parameters from the magnetic measurements. The Preisach model has been widely used for modeling magnetic hysteresis loops. Whilst the phenomenological nature and mathematic generality of the model has been well described [1] the interpretation of the Preisach function remains more or less non-physical in that continuous magnetic materials are modeled as an ensemble of discrete and independent magnetic particles. The Preisach function is usually regarded as the weight function for a particle that has a rectangular hysteresis loop with given switch-up (alpha) and switch-down (beta) values. The Preisach function is usually not explicitly evaluated or sometimes only discretely reconstructed from certain sets of measured hysteresis curves [2]. Non-physical and/or non-unique reconstruction (i.e. minus weight value) has been reported e.g. [3]. There have also been several attempts of purely mathematically approximating the Preisach function with e.g. Gaussian and/or Lorentzian functions [4] . However, one cannot predict major/minor loops for given microstructures or inversely evaluate microstructural parameters with these models. In this paper a modified Preisach model with the Preisach function formulated based on microstructural feature distribution and probability theory has been developed to model major/minor loops of ferromagnetic steels. Ferrite grains and precipitates within the grains have been selected as the two microstructural features to demonstrate the model. The grain size and misorientation distribution and the size and inter-particle spacing distribution of the precipitates are introduced to formulate the Preisach function. The model has proved capable of capturing the different effects of these microstructural features on the different parameters of the modeled major/minor loops.**---**This work was carried out with financial support from EPSRC under Grant EP/K027956/1.

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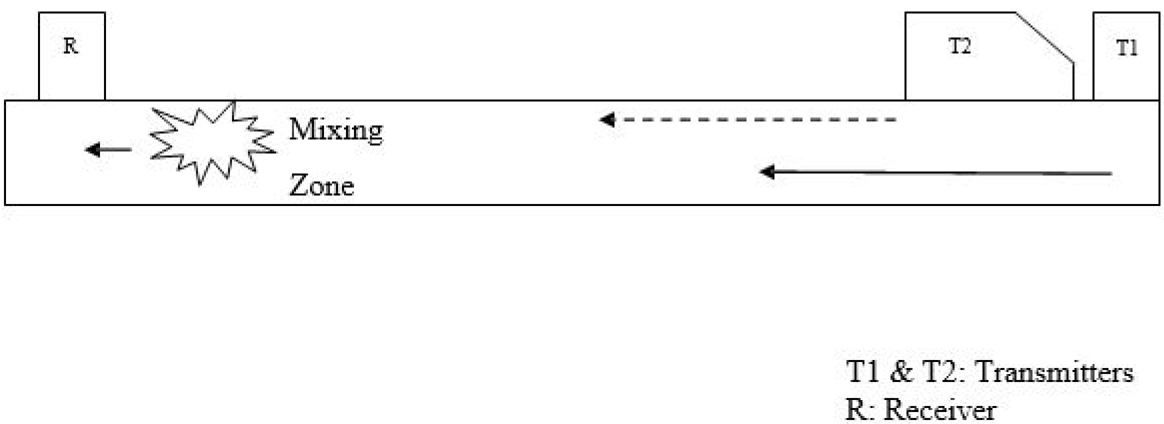
10:50 AM

Experimental Study of Ultrasonic Lamb Wave Mixing During Tempering of Modified 9Cr-1Mo Steel

---**Avijit Kr Metya**[1,2], M. Ghosh[1], N Parida[1], and Krishnan Balasubramaniam[2], [1]MST Division, CSIR-National Metallurgical Laboratory, Jamshedpur-831007, India; [2]Center for NDE, Mechanical Engineering Department, IIT-Madras, Chennai-600036, India

---An approach has been made to study the tempering effect on modified 9Cr-1Mo steel by mixing two Lamb waves. As-received material was normalized at 1080°C and then tempered in temperature range of 600-850°C with a step size of 50°C for 1.5 hrs and followed by furnace cooling. Two types of Lamb waves were mixed under resonance conditions to generate a mixing harmonic wave of sum frequency of the two fundamental waves and nonlinear ultrasonic parameter β was determined from the mixing wave at each temperature and correlated with microstructural characteristics like size of precipitate and density of dislocation. It was seen that acoustic nonlinearity parameter (β) was sensitive towards precipitate-matrix coherency strain, generated during tempering.



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11:10 AM

Elastic Constants Measurements of a Ti–7al Using Resonant Ultrasound Spectroscopy

---**R. A. Adebisi**[2], S. Sathish[2], andP.A. Shade[1], [1]Air Force Research Laboratory, Wright Patterson AFB OH 45433; [2]University of Dayton Research Institute, Dayton OH, 45469

---Resonant ultrasound spectroscopy (RUS) measurements have been performed to determine the complete set of elastic constants of a single-phase (α, HCP crystal structure) titanium alloy, Ti-7Al. RUS is a nondestructive evaluation method that measures the mechanical resonance of solids and uses the resonance frequencies to extract a complete set of elastic constants of the solid material. One of the advantages of the RUS method is its applicability to small single crystals. Titanium alloys are widely employed in aerospace, energy and biomedical applications because of their high specific strength, low density, high service temperature, good fracture toughness and corrosion resistance. The elastic constants of titanium alloys vary substantially depending on manufacturing history and composition. In addition, available data on the elastic constants of titanium alloys is limited due to challenges in processing and growing single large crystals. The elastic stiffness matrix is a very important input parameter in both deformation modeling frameworks and conversion of high-precision elastic strain measurements into stress. Hence, accurate knowledge of the elastic constants is critical to the performance of predictive computational mechanics models. Complete set of elastic constants measured using RUS will play an important role in understanding the deformation behavior of model materials like Ti-7Al.

Session 38

SESSION 38

EDDY CURRENT II

John Bowler and Harold Sabbagh, Chairpersons
Nicollet D3

8:30 AM **NDE Damage Characterization of Complex Aircraft Structures by Inverse Methods: Advances in Multiscale Models**
---R. Kim Murphy, **Harold A. Sabbagh**, Elias H. Sabbagh, and Liming Zhou, Victor Technologies, LLC, Bloomington, IN 47407-7706; William Bernacchi, Minds-Edge LLC, Indianapolis, IN 46268; John C. Aldrin, Computational Tools, Gurnee, IL 60031; David Forsyth, Texas Research Institute Austin, Austin, TX 78733-6201; Eric Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB, OH 45433-7817

8:50 AM **Identification of Rebars in a Reinforced Mesh Using Eddy Current Method**
---Paweł Karol Frankowski, Ryszard Sikora, and **Tomasz Chady**, West Pomeranian University of Technology, Szczecin, Poland

9:10 AM **Eddy Current Tube Inspection Simulation Using a Rotary Probe**
---**J. R. Bowler** and T. Wu, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:30 AM **Inversion Methods for Alternating Current Potential Drop Measurements**
---**J. R. Bowler**, Y. Ji, and R. Quddes, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Application of Induced Circumferential Current for Cracks Inspection on Pipe String**
---Xin'an Yuan, Wei Li, **Xiaokang Yin**, Guoming Chen, and Jiuhao Ge, China University of Petroleum, Center for Offshore Equipment and Safety Technology, Qingdao 266580, China

10:10 AM ***Break***

10:30 AM **Analytical Solution for the Effect of the Permitivity of Coating Layer on the Eddy Current Generated in an Aluminum Sample by EMAT**
---**Sun Feiran**, Sun Zhenguo, and Chen Qiang, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, China
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10:50 AM **Effects of Magnetic Interferences in Magnetostrictive Patch Transducers on Ultrasonic Signals**
---**Jun Kyu Lee**, Joo Kyung Lee, and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering and Institute of Advanced Machinery and Design, 1 Gwanak-ro, Gwanak-gu, Seoul, 151-742, Republic of Korea

11:10 AM **The Optimal Impedance of an EMAT**
---Julio A Isla, Matthias Seher, Richard E. Challis, and Frederic Cegla, Imperial College London, NDE Group, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

11:30 AM ***Adjourn***

8:30 AM

NDE Damage Characterization of Complex Aircraft Structures by Inverse Methods: Advances in Multiscale Models

--R. Kim Murphy, **Harold A. Sabbagh**, Elias H. Sabbagh, and Liming Zhou, Victor Technologies, LLC, Bloomington, IN 47407-7706; William Bernacchi, Minds-Edge LLC, Indianapolis, IN 46268; John C. Aldrin, Computational Tools, Gurnee, IL 60031; David Forsyth, Texas Research Institute Austin, Austin, TX 78733-6201; Eric Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB, OH 45433-7817

---The use of dual integral equations and anomalous currents allows us to efficiently remove 'background effects' in either forward or inverse modeling. This is especially true when computing the change in impedance due to a small flaw in the presence of a larger background anomaly. It is more accurate than simply computing the response with and without the flaw and then subtracting the two nearly equal values to obtain the small difference due to the flaw. The problem that we address in this paper involves a 'SplitD' probe that includes complex, noncircular coils, as well as ferrite cores, inserted within a bolt hole, and exciting both the bolt hole and an adjacent flaw. This introduces three coupled anomalies, each with its own 'scale'. The largest, of course, is the bolt hole, followed (generally) by the probe, and then the flaw. The overall system is represented mathematically by three coupled volume-integral equations. We describe the development of the model and its code, which is a part of the general eddy-current modeling code, VIC-3D®. We will give initial validation results, as well as a number of model computations with flaws located at various places within the bolt hole.---This work was supported by the Air Force Research Laboratory through SBIR Contract FA8650-13-C-5011 with Victor Technologies, LLC.

8:50 AM

Identification of Rebars in a Reinforced Mesh Using Eddy Current Method

---**Paweł Karol Frankowski**, Ryszard Sikora, and Tomasz Chady, West Pomeranian University of Technology, Szczecin, Poland

---The paper presents system and method for detection and evaluation of steel reinforcement bars in complex concrete structures. An association rule learning algorithm is utilized to identify relations between measured voltage waveform and structure parameter. The experimental verification of the developed technique is done and the selected results will be presented. The reinforced concrete has been used for structures of every type and size for over a century. Structures of this kind relatively frequently requires inspection. Usually after the concrete has hardened. The point of the inspections is to determine whether the structure is suitable for its designed use, estimate the condition or remaining lifetime. Used in investigations system consists of four subsystems: XYZ scanner, excitation subsystem, data acquisition subsystem and controlling computer. Exciting coils of the differential E-shape eddy current transducer are powered from two independent function synthesizers. System collects data during the transducer movement above the structure surface as a voltage induced on the pickup coil. Previous research proves that the eddy current method can be successfully used to evaluate many structure parameters. The identification may involve: rebar diameter (D), physical properties of rebar (represented by rebar class), and rebar location including thickness of the concrete cover (*h*). However, rebars in the concrete structure are usually connected in a reinforcement mesh. This poses the problem because the eddy current transducer can interact with many rebars at once. Therefore, it is very important to correctly select the transducer size. The small transducers have a good spatial resolution and can identify rebars parameters even if between them is a small distance, but their sensitivity is low. On the other hand, the shape of output voltage provides information about rebars even if signals caused by two bars overlap each other. Studies show that, there is a possibility to use the same database in both cases, during the identification of structure parameters with thick reinforced mesh and with single rebar. The most important is to properly create and select the identification attributes. For this purpose the association rule learning is proposed. Association rule learning is a method for discovering interesting relations between attributes in large databases. This method can be used also to find the relation between measurement results and the parameters of the reinforcement structures. Used algorithm is based on the analysis of shape factors, and maximal voltage waveform magnitude.

9:10 AM

Eddy Current Tube Inspection Simulation Using a Rotary Probe

---**J. R. Bowler** and T. Wu, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---We have developed an improved numerical model of eddy current interactions with tubes using volume integral methods in order to establish a foundation for applying inversion techniques to reconstruct flaws from probe impedance measurement and from data obtained using magnetic field sensors. Initially we derived analytical expressions for the quasi-static time-harmonic electromagnetic field a circular current filament via the transverse magnetic potential expressed in terms of a single layer potential. This is then used to deduce the field of an induction coil near a conductive tube, the axis of the coil having an arbitrary direction. The field for both internal and external coils have been determined and used to deduce coil impedance variations with frequency and position due to induced current including the effects of flaws. The surrounding magnetic field is also computed to allow for the possibility deducing flaw dimensions from magnetic field sensors for measurements.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University

9:30 AM

Inversion Methods for Alternating Current Potential Drop Measurements

---**J. R. Bowler**, Y. Ji, and R. Quddes, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---An analytical expression has been found for the voltage between the pickup electrodes of a four point probe in contact with a multi-layered conductor injected with alternating current. The expression is used to interpret four point probe measurements on metal plates whose material properties vary with depth. By assuming that the current is injected/extracted at points on the surface, the solution is expressed in terms of a Green's function for the layered structure. Special cases are the conductive half-space, a conductive plate and a half-space with a single layer. In the general case of an arbitrary number of layers, the formula is useful for the evaluation of surface treatments which alter the conductivity and permeability of the material with depth. Examples of such treatments are shot peening and case-hardening. We describe how the theory can be used to determine the case depth of case-hardened ferromagnetic steels from multi-frequency four point alternating current potential drop measurements.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University

9:50 AM

Application of Induced Circumferential Current for Cracks Inspection on Pipe String

---Xin'an Yuan, Wei Li, **Xiaokang Yin**, Guoming Chen, and Jiuhao Ge, China University of Petroleum, Center for Offshore Equipment and Safety Technology, Qingdao 266580, China

---Pipe strings (such as drill pipe, tube, pipeline, and riser) are critical facilities in oil & gas industry, which are highly susceptible to cracks caused by stress corrosion and fatigue damage [1]. A full 360°circumferential current induced by a coaxial excitation coil is proposed for inspection of axial and transverse cracks on pipe strings [2]. As shown in Fig. 1, 3D finite element model of excitation coil and pipe string with cracks is employed to analyze distribution of the induced circumferential current near axial and transverse cracks on pipe string. Characteristic signals of axial and transverse cracks are extracted using the finite element model. The induced circumferential current test system is set up and crack inspection experiments are carried out. The results show that characteristic signals obtained in experiments are in good agreement with the simulation results. Due to 360°broad excitation region, both axial and transverse cracks can be efficiently detected on pipe string in a one-pass scanning with sensor array. The induced circumferential current can be applied to detect cracks on pipe strings in corrosive environment, such as drill pipes, tubes, pipelines and other fields.**---**The work is funded by the Scientific and Technological Developing Project of Shandong province (No. 2013GHY11513), the National Natural Science Foundation of China (No. 51205412 and No. 50905187), the China Postdoctoral Science Foundation (No. 2013M540568 and No.2014T0666), the Postgraduate Innovation Project of China University of Petroleum (No. Y14040).

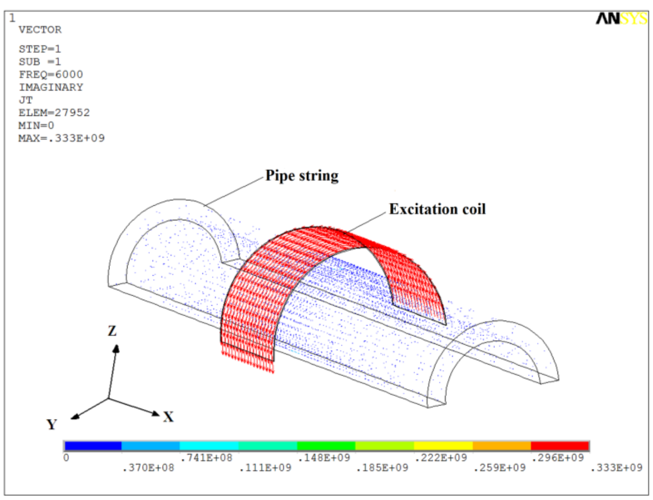

Figure 1. Structure of 3D finite element model.

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10:30 AM

Analytical Solution for the Effect of the Permittivity of Coating Layer on the Eddy Current Generated in an Aluminum Sample by EMAT

---**Sun Feiran**, Sun Zhenguo, and Chen Qiang, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, China

---In order to improve the ultrasonic wave amplitude excited by electromagnetic acoustic transducers (EMATs), many researchers have proposed analytical models of EMATs and analyzed the effect on transduction efficiency of parameters such as the bias magnetic flux density, the size and the shape of the exciting coil, the lift off, the conductivity of sample and so on. However, they always ignored the displacement current and the effect of the permittivity of the air or the metal sample ($\mu\varepsilon\omega^2 A$) in equation (Eq.1), due to its low permittivity [1-3]. Nevertheless, in nondestructive testing and evaluation field currently, more durable dielectric materials are replacing or coating with metals in many applications which has a much higher permittivity than air or metal sample so that the effect of permittivity cannot be ignored. Therefore, based on an analytical model, the effect of the permittivity of coating layer on the eddy current generated in an aluminum sample by EMAT operating on the Lorentz principle has been studied shown as Fig. 1. The analytical analysis indicates that the eddy current density excited by the spiral coil of EMAT decreases with the permittivity of the coating layer increases, and it has much relation to the thickness of the coating layer and the exciting frequency, which is verified by the simulation result.

$$\frac{\partial^2 A}{\partial r^2}+\frac{1}{r}\frac{\partial A}{\partial r}+\frac{\partial^2 A}{\partial z^2}-\frac{A}{r^2}=-\mu i_0+j\omega\mu\sigma A-\mu\varepsilon\omega^2 A-\mu\{\frac{\partial}{\partial r}(\frac{1}{\mu})\frac{1}{r}\frac{\partial(rA)}{\partial r}+\frac{\partial}{\partial z}(\frac{1}{\mu})\frac{\partial A}{\partial z}\} \quad (1)$$

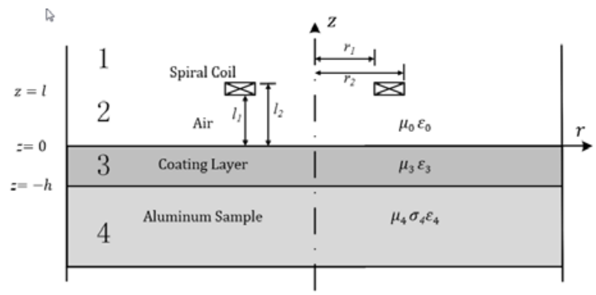

Figure 1. Model of spiral coil at a distance above a coating layer on an aluminum sample.

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3. G. Zhai, K. Wang, Y. Wang, R. Su, and L. Kang, “Modeling of Lorentz forces and radiated wave fields for bulk wave electromagnetic acoustic transducers”, Journal of Applied Physics **114**(5) 054901 (2013).

10:50 AM

Effects of Magnetic Interferences in Magnetostrictive Patch Transducers on Ultrasonic Signals

---**Jun Kyu Lee**, Joo Kyung Lee, and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering and Institute of Advanced Machinery and Design, 1 Gwanak-ro, Gwanak-gu, Seoul, 151-742, Republic of Korea

---When multiple magnetostrictive patch transducers (MPTs) are placed in close proximity for high-resolution imaging, mutual interferences among them may affect their performance. Because MPTs are operated by applying and sensing magnetic fields, the interferences among the transducers become an issue. However, no investigation, either theoretical or experimental, on magnetic interferences in MPTs has been performed. In this research, we investigate the effects of magnetic interferences on the performance of MPTs and propose methods to minimize them. The interference phenomenon of static biasing magnetic field as well as that of dynamic actuating magnetic field is numerically and experimentally examined. It was found that the interference by the dynamic field results in undesirable cross-talk in a signal measured by a receiving MPT and that the interference by the static field distorts ultrasonic waves generated by a transmitting MPT. We investigated how much the cross-talk signals are affected by the distance between the transmitter and the receiver and suggested a method to minimize the cross-talk. Then, we analyzed distortions in the radiation pattern of the Lamb waves under the influence of the static magnetic field interference and then proposed the minimum distance between the transmitters to avoid the interference. In all cases, a set of experiments were conducted and the experimental results were verified by semi-analyses. While the specific transducer, an omni-directional Lamb wave magnetostrictive patch transducer (OL-MPT) [1], was used in this research, the findings can be applied to any type of magnetostrictive patch transducers.---This research was supported by the National Research Foundation of Korea (NRF) grant (No. 2015-021967 and No. 2014M3A6B3063711) funded by the Korea government (MSIP).

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11:10 AM

The Optimal Impedance of an EMAT

---**Julio A Isla**, Matthias Seher, Richard E Challis, and Frederic Cegla, Imperial College London, NDE Group, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Electromagnetic-acoustic transducers (EMATs) are attractive for non-destructive inspections as contactless sensors. This advantage comes at a high cost in sensitivity and therefore it is important to optimise every aspect of an EMAT. Regardless of the transduction mechanism (e.g. Lorentz force or magnetostriction) the signal strength produced by EMATs depends on the coil impedance. There is very little literature on how to select the best coil impedance to maximise the signal strength and signal-to-noise ratio and this paper addresses this gap. A transformer circuit is used to model the interaction between the EMAT coil and the eddy currents that are generated beneath the coil in the conducting specimen. Expressions for the optimal impedances for maximum efficiency and maximum power transfer on transmission are presented. The noise generated by the coil and the receive amplifier on reception are investigated and identified as important contributors to the signal-to-noise ratio.---The authors would like to acknowledge funding from the Engineering and Physical Sciences Research Council, IC Trust, Shell and Petrobras.

Session 39

SESSION 39
STRUCTURAL HEALTH MONITORING
Bernd Köhler, Chairperson
Lakeshore A

8:30 AM **Scattering of High Order Guided Wave Modes Around a Through Thickness Circular Hole**
---**Christophe Travaglini**[1], Christophe Bescond[2], Demartonne Ramos Franca[1], Silvio E. Kruger[2], Martin Viens[1], and Pierre Belanger[1]; [1]Département de Génie Mécanique, École de Technologie Supérieure, 1100 rue Notre-Dame Ouest, Montréal (Québec), H3C 1K3, Canada; [2]Conseil National de Recherches Canda, 75 boulevard de Mortagne, Boucherville (Québec), J4B 6Y4, Canada

8:50 AM **Testing and Control of Residual Stress for Aluminum Alloy**
---**Chunguang Xu**, Wentao Song, Qinxue Pan, Huanxin Li, and Shuai Liu, Beijing Institute of Technology, 5th South Zhongguancun Street, Haidian District, Beijing, China, 100081 Beijing, China

9:10 AM **OPEN**

9:30 AM **Application of Ultrasonic Thickness Measurement Technique for Evaluation of Copper Stave in the Blast Furnace**
---**Sang-Woo Choi**, Nam-Ho Shin, and Tae-Hwa Choi, 6261, Donghaean-ro, Nam-gu, Pohang-si, Gyengbuk 790-300, POSCO, Pohang, South Korea

9:50 AM **Rapid Non-Contact Guided Ultrasonic Method for Inspection of Hidden and Curved Regions in Composite Aerospace Structures**
---Dileep Koodalil and **Krishnan Balasubramaniam (presented by Rabi Panda)**, Indian Institute of Technology Madras, Centre for Non-destructive Evaluation and Department of Mechanical Engineering, Chennai-600036, Tamil Nadu, India

10:10 AM ***Break***

10:30 AM **Locating Damages in a Complex Structure Using a Single Fixed Ultrasonic Transducer**
---**S. Rodriguez**[1,2], M. Veidt[3], M. Castaings[1], Eric Ducasse[1], and M. Deschamps[1], [1]Univ. Bordeaux, 12M, UMR 5295, F-33400, Talence, France; CNRS, 12M, UMR 5295, F-33400, Talence, France; Bordeaux INP, 12M, UMR 5295, F-33400, Talence, France; Arts et métiers Paris Tech, 12M, UMR 5295, F-33400, Talence, France; [2]Cooperative Research Centre for Advanced Composite Structures, I/320 Lorimer Street, Port Melbourne, Victoria, 3207, Australia; [3]School of Mechanical and Mining Engineering, The University of Queensland, Brusbane St. Lucia, Queensland 4072, Australia

10:50 AM **Shear Horizontal Piezoelectric Fiber Patch Transducers (SH-PFP) for SHM Applications**
---**Bernd Köhler**, Uwe Lieske, and Frank Schubert, Fraunhofer Institute for Ceramic Technologies and Systems, Branch Materials Diagnostics IKTS-MD, Dresden, Germany

11:10 AM **Multi-Parameter POD for a Guided Waves Based SHM Approach for Lightweight Materials**
---**A. Gianneo**, M. Carboni, and M. Giglio, Dipartimento di Meccanica, Politecnico di Milano, Via La Masa 1, 20156 Milano

11:30 AM ***Adjourn***

8:30 AM

Scattering of High Order Guided Wave Modes around a Through Thickness Circular Hole

---**Christophe Travaglini** [1], Christophe Bescond [2], Demartonne Ramos França [1], Silvio E. Kruger [2], Martin Viens [1] and Pierre Belanger [1] ; [1]Département de Génie Mécanique, École de Technologie Supérieure, 1100 rue Notre-Dame Ouest, Montréal (Québec), H3C 1K3, Canada; [2]Conseil National de Recherches Canada, 75 boulevard de Mortagne, Boucherville (Québec), J4B 6Y4, Canada

---Ultrasonic guided waves have the ability to propagate long distances with minimal attenuation, this makes them particularly interesting in structural health monitoring (SHM) applications. Using the baseline subtraction approach, the signal from a defect free structure is compared to the actual monitoring signal to detect and locate defects. There are many scientific publications on low frequencies guided waves for SHM purposes and the interaction between guided wave fundamental modes and defects is also well documented. There is however a very limited number of studies on high order modes. High frequency guided waves may enable the detection of smaller cracks relative to conventional low frequency guided waves SHM. The main difficulty at high frequency is the existence of several modes with different velocities. This study investigates the scattering of high order guided wave modes around a through-thickness hole with a view to develop a highly sensitive SHM method. A 3D finite element model of a 600 mm × 600 mm × 1.6 mm aluminum plate was used to determine the scattering of cracks on the circumference of a through-thickness hole in the middle of the plate. Crack properties such as orientation, length and depth were studied. A subset of the finite element simulations were validated against experimental results. The experimental setup comprised a film type PZT actuator bonded on the side of the plate and a laser interferometer detector. An input signal centered at 4 MHz was used in all simulations and experiments.---The authors would like to acknowledge the Consortium for Research and Innovation in Aerospace in Québec, the NRC program AERO21 and our industrial partners, Bombardier and L3-MAS, for their generous support.

8:50 AM

Testing and Control of Residual Stress for Aluminum Alloy

---**Chunguang Xu**, Wentao Song, Qinxue Pan, Huanxin Li, and Shuai Liu, Beijing Institute of Technology, 5th South Zhongguancun Street, Haidian District, Beijing, China, 100081 Beijing, China

---Residual stress has significant impacts on the performance of aluminum alloy components [1]. It can either improve or damage the performance and characteristics of the components, especially in terms of its strength, fatigue life, corrosion resistance and dimensional stability. It has been a difficulty and hot issue that how to test and regulate the residual stress status of the surface or a certain depth of aluminum alloy components quickly and nondestructively [2]. Based on acoustoelasticsticity theory, the relationship between velocity and direction of ultrasonic propagation and stress is researched and residual stress ultrasonic testing and calibration system is built. Uses it to test aluminum alloy plate of friction stir welding, and obtained the distribution map of residual stress around the weld as Fig. 1. Further, a technique called high-energy ultrasonic method for regulate of residual stress in aluminum alloy components is tested and confirmed. Fig. 2 shows the change of residual stress before and after regulation. As result, due to the reduce of residual tension stress, the anti-fatigue strength and anti-corrosion, anti-wear performance of the surface and interior regions of aluminum alloy components can be enhanced [3].---This work was sponsored by Natural Science Foundation of China (No. 51275042).

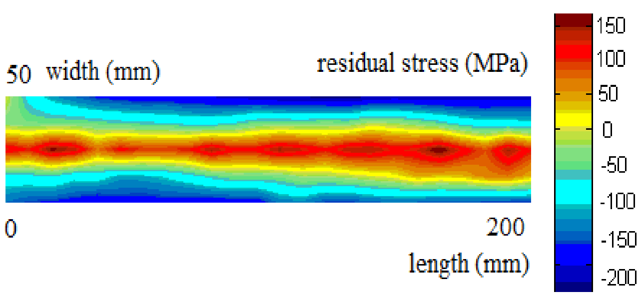

Figure 1. Distribution map of residual stress

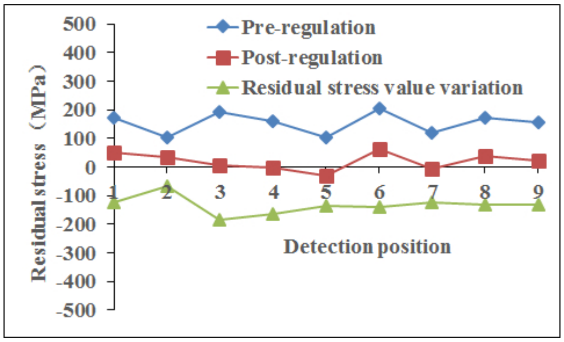

Figure 2. Change of residual stress

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3. N. S. Rossini, M. Dassisti, K. Y. Benyounis, et al. "Methods of measuring residual stresses in components," Material and Design, Vol. 35, pp. 572-588 (2012).

9:10 AM

Prognostic Algorithms for Prediction of Remaining Useful Life of Aerospace Structures

---Taha Ali, Waleed Bin Yousuf, Kiran Aslam, and Tariq Khan, National University of Sciences and Technology, Department of Electronics and Power Engineering, Karachi, Sindh, Pakistan 75350

---Prediction of remaining useful life (RUL) of aerospace structure allows airlines to plan repair/replacement activities well in time. This allows lower probability of failure in service and lower downtime of aircrafts. Accurate RUL prediction is possible through usage of effective prognostic algorithms, based on historical trend and underlying mechanical degradation / fatigue models. A Particle Filter (PF) [1] based prognostic algorithm is proposed to predict posterior PDF of flaw size in future. PF allows us to use non-linear state-transition and measurement functions, along with non-Gaussian / multimodal noise distributions. RUL can be computed based on estimated posterior PDF [2]. The proposed algorithm uses actual mechanical fatigue models as degradation models and historical flaw growth trend for updation of posterior PDF. Mechanical fatigue propagation models based on Paris Law are used for a realistic estimate of the state transition function. The proposed algorithm is applied on actual aerospace historical data of an in-service Airbus A320 aircraft. A common flaw is the damage around edges of countersunk holes on the wings due to mechanical fatigue and corrosion. Accurate prediction of flaw propagation / RUL helps reduce the number of regular checks and repairs required and in turn reduces the downtime of the aircraft. Details of the implementation and the results will be presented at the conference and in full paper. The authors would like to acknowledge generous support of the National ICT R&D fund, Pakistan.

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9:30 AM

Application of Ultrasonic Thickness Measurement Technique for Evaluation of Copper Stave in the Blast Furnace

---**Sang-Woo Choi**, Nam-Ho Shin, and Tae-Hwa Choi, 6261, Donghaean-ro, Nam-gu, Pohang-si, Gyengbuk 790-300, POSCO, Pohang, South Korea

---The blast furnace producing molten iron has the cooling plate and the stave for protecting steel shell. Benefits of the copper staves are thin wall thickness, stable operation and high heat conductivity. Coincidentally, recent blast furnaces with the copper staves experienced a disadvantage that is thickness reduction caused by wearing. Since the staves are attached on inner wall of the furnace, the staves are inaccessible. Thickness measuring techniques were proposed for the diagnosis of the copper staves [1]. There are three steps in measuring residual thickness of the copper stave. First step is on-line monitoring of the thickness at limited staves with an embedded ultrasonic transducer. On-line monitoring information can show thickness reduction trend. Second step is manual thickness measuring at selected staves with a special columnar ultrasonic transducer. According to the thickness reduction trend from the on-line monitoring results, target staves should be measured are selected among unlimited number of the staves. Third step is thickness profile measurement for detail diagnosis of a weak stave. In the first and second steps, the stave thickness can be measured only at the inlet/outlet port. However, there are 4 or 5 long cooling lines in the one stave and the thickness deviation should be examined. In the measuring thickness profiles, the ultrasonic transducer is put into the cooling line of the stave and the transducer scan wall of the cooling during climbing up. (Fig. 1)

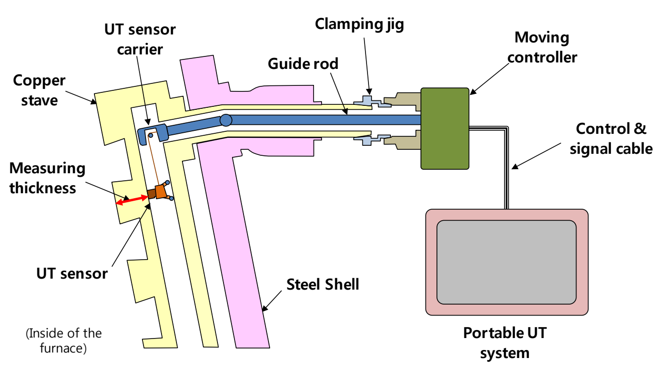

Figure 1. Schematic diagram of stave thickness profile measuring system.

Reference:

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9:50 AM

Rapid Non-Contact Guided Ultrasonic Method for Inspection of Hidden and Curved Regions in Composite Aerospace Structures

---Dileep Koodalil and **Krishnan Balasubramaniam**, Indian Institute of Technology Madras, Centre for Non-destructive Evaluation and Department of Mechanical Engineering, Chennai-600036, Tamil Nadu, India

---The use of composites in stiffened aerospace air-frame structures introduces complex geometries and hidden regions that are vulnerable to defects during manufacturing and damage during service. Inspections of such structures are cumbersome and time consuming, but are of a great concern to aerospace industry since the criticality of defects/damage in these regions can lead to unexpected failures and downtime. This work presents a technique for rapid non-contact inspection of curved and hidden regions in stiffened composite components. Air-Coupled guided wave ultrasonic inspection in was employed. The probes were configured in order to excite Anti-symmetric plate mode (A0). The direct A0 modes as well as the mode converted S0 modes were detected using a receiver probe. Different modes of reception i.e. in through transmission, in reflection, etc. as well as probe position configurations viz. both receiver and transmitter on the same side, receiver and transmitter on opposite side, etc. were explored. The technique was found to have the capability to detect and locate defects of the delamination type in the hidden and curved regions of such stiffened composite components. Additionally, finite element (FE) models were used to visualize guided wave propagation and its interaction with defects in such curved and hidden regions for improved interpretation of the as-received signals from the experiments. The technology has the potential to significantly improve the inspection capabilities for complex regions in aerospace components.

10:30 AM

Locating Damages in a Complex Structure Using a Single Fixed Ultrasonic Transducer

---S. Rodriguez[1,2], M. Veidt[3], M. Castaings[1], Eric Ducasse[1], and M. Deschamps[1], [1]Univ. Bordeaux, I2M, UMR 5295, F-33400, Talence, France; CNRS, I2M, UMR 5295, F-33400, Talence, France; Bordeaux INP, I2M, UMR 5295, F-33400, Talence, France; Arts et métiers Paris Tech, I2M, UMR 5295, F-33400, Talence, France; [2]Cooperative Research Centre for Advanced Composite Structures, 1/320 Lorimer Street, Port Melbourne, Victoria, 3207, Australia; [3]School of Mechanical and Mining Engineering, The University of Queensland, Brisbane St Lucia, Queensland 4072, Australia

---Detecting and locating defects in a plate is usually performed using multiple transducers and methods that are based on the measurement of the wave travelling directly from the defect to the transducer. The acoustic signatures of the interaction between the structure itself and the defects, such as the reflections on the boundaries, are generally discarded from the signal. All this physical information is then not used. This presentation deals with the experimental application of the topological imaging method that takes advantages of all the information included in the multiple reflections between the boundaries of the structure and the defects. The application of the method is based on a preliminary measurement of the impulse response of the inspected structure before this structure is damaged. The impulse response measurement is restricted to a defined region of interest and the structure is excited with a single fixed transducer. This preliminary measurement can be considered as a general acoustic calibration of the inspected structure that is performed once and for all, in the present case with a Laser Doppler velocimeter. The structure is then inspected with the same single transducer and, if any, damages are located in the region of interest. The experimental results obtained with this one-channel topological imaging method show accurate location of a single small defect and of multiple small defects. The resolving power obtained is near from the theoretical limit of half a wavelength. These results demonstrate that the method has high potential for complex structures in general and for SHM applications involving a limited number of embedded transducers.

10:50 AM

Shear Horizontal Piezoelectric Fiber Patch Transducers (SH-PFP) for SHM Applications
---Bernd Köhler, Uwe Lieske, and Frank Schubert, Fraunhofer Institute for Ceramic Technologies and Systems, Branch Materials Diagnostics IKTS-MD, Dresden, Germany

---Horizontally polarized elastic shear waves (SH) can advantageously be applied in Nondestructive Testing (NDT) and in Structural Health Monitoring (SHM). This wave type does not show mode conversion when reflected by surfaces (parallel to the plane of incidence) and while propagating along surfaces. Therefore in NDT the echo signals are relatively easy to interpret. Also leaky radiation into adjacent media like fluids is suppressed, resulting in less energy loss and larger range of the application. In plates the lowest order horizontal plate wave (SH0) shows no dispersion and is therefore best suited for SHM and for long range NDT of pipes. Horizontally polarized waves can be excited directly in the material by electromagnetic transducers (EMAT). These transducers are relatively large and do not work on nonconductive materials. Piezoelectric transducers have to be coupled to the surface by gluing or by a high viscosity liquid to be able to transfer the shear forces. Moreover, conventional NDT shear transducers contain a large seismic mass which is a big disadvantage for SHM in lightweight materials. Piezoelectric fiber patch (PFP) materials are well known in adaptronics. As shown previously by several authors, it is also possible to modify them for excitation and detection of symmetric (S_n) and antisymmetric (A_n) lamb modes in plates, allowing SHM with guided elastic waves. Today, horizontal polarized modes are excited only as byproduct of A_n- und S_n-excitation in form of edge waves. Recently, a new sensor concept for SH wave excitation and reception based on PFP was proposed and verified by simulation of the emitted wave field [1]. This concept is complemented in the present contribution by new variants. Additionally, we give first experimental prove that these transducer excite SH_0 plate waves with strong selectivity. These wave fields are measured by Scanning Laser Vibrometry and we compare the measured data with simulation results based on the Elastodynamic Finite Integration Technique (EFIT). The possible applications of the new sensor type in guided elastic wave monitoring are discussed.

Reference:

1. Schubert, F.; Köhler, B. & Lieske, U.
   A Novel Sensor Design for Generation and Detection of Shear-Horizontal Waves Based on Piezoelectric Fibres, Proceedings of the European Conference on Nondestructive Testing, 2014 Praha.

11:10 AM

Multi-Parameter POD for a Guided Waves Based SHM Approach for Lightweight Materials

---**A. Gianneo**, M. Carboni, and M. Giglio, Dipartimento di Meccanica, Politecnico di Milano, Via La Masa 1, 20156 Milano

---Besides an extensive literature review and publications about Guided Waves propagation, interaction and numerical simulation in plate like structures made of metals and composite systems, lack of information are provided regarding its reliability in SHM approaches. Typically, because of uncertainty in the inspection process, capability of NDT systems is expressed by means of suitable POD Curves. Based on Berens' model a monotonic expression is established between the Probability of Detection and the flaw size. Although the uncertainty factors differ from a NDT inspection technique and a SHM approach, the same mathematical framework can be implemented. Hence, the authors investigated the application of a recently developed, within NDT purposes, Multi Parameter POD approach for a GWs based SHM: numerical simulations as well as experimental data from flawed plates combine to bring about a master POD. Once established, it can be decomposed in the single key factor as flaw size, orientation, structural attenuation.

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QNDE Future Dates and Locations

July 25-31, 2016
Georgia Tech Hotel and Conference Center
Atlanta, Georgia

July 16-21, 2017
Provo, Utah

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